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A paper presented at the 29th Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June 25, 1912.

CORONA LOSSES BETWEEN WIRES AT HIGH VOLTAGES

BY C. FRANCIS HARDING

Much has been written within the last few years upon the subject of atmospheric or so-called "corona" losses between wires at high voltages. Particular interest has been aroused in connection with this loss because of the fact that since the advent of the suspension insulator and the condenser type of transformer bushing the loss due to corona has become the limiting factor in the increase of transmission line voltages. The number of tests which have been made to determine the exact value of such loss under varying conditions of line construction, weather conditions, etc., which have been recognized to be free from a relatively large probability of error, have been too small to warrant final conclusions, particularly with regard to the accuracy of empirical formulas derived therefrom. The formulas suggested for the determination of corona loss and critical voltage have not been applied to other available tests nor a comparative summary made of such tests upon a common basis.

It is the object of this paper, therefore, first to set forth as a progress report the results of tests recently performed at Purdue University by a method differing in some respects from any previously published and to compare the results obtained by various observers upon such a basis as to aid in the early confirmation of formulas which may be generally used in transmission line design.

Experimental Transmission Line

The line upon which the tests were made was constructed for the purpose and was about 1380 ft. in length, made up of

three spans of approximately equal length. Steel poles with 18-ft. cross arms supported the line through the agency of five-part suspension insulators. The insulators were so mounted that the wire spacing could be easily changed.

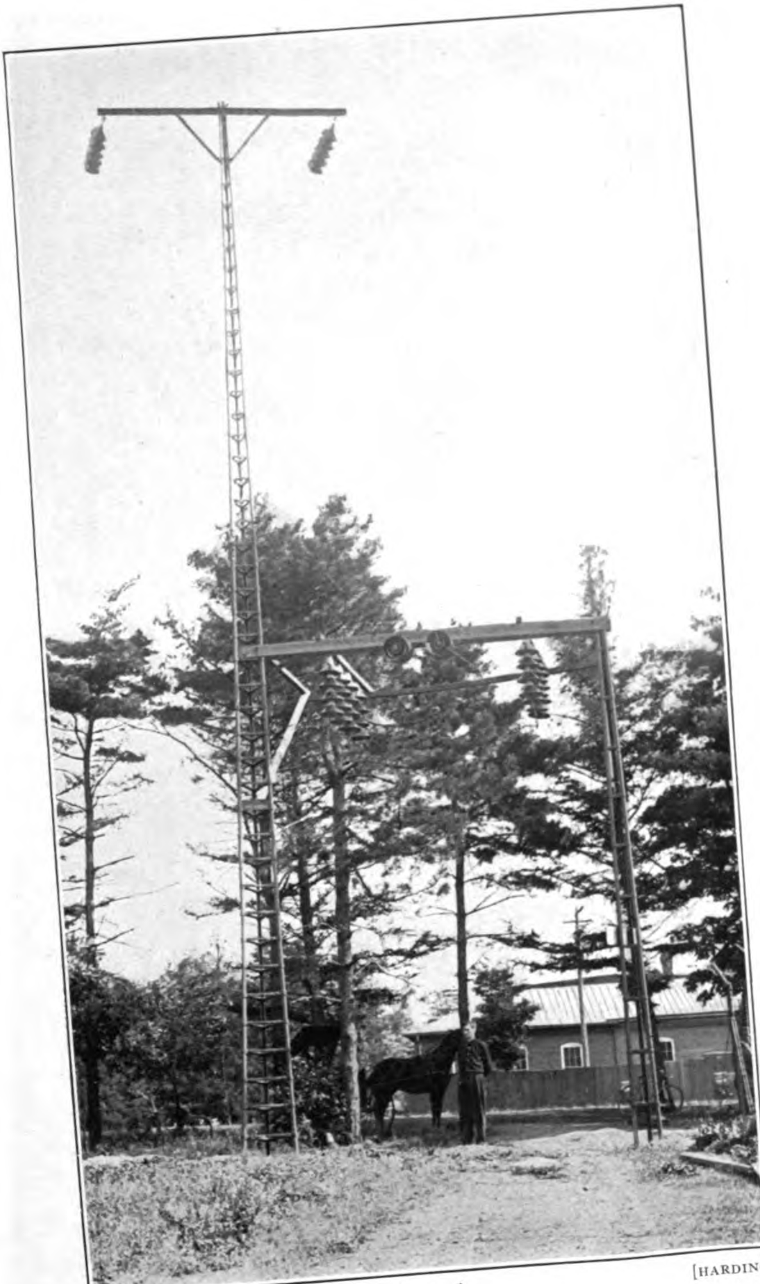
An insulator rack, Fig. 1, similar in all respects to the insulators upon the line but containing but a few feet of line wire was provided in order that the losses over the insulators might be separately measured and deducted. Jumpers surrounding the strain insulators were so designed that the line could be readily reached from the ground by means of a pole and connected to or disconnected from the insulator rack and feeder so that line and rack measurements could be made in rapid succession and therefore under the same weather conditions.

Method

The method employed was not unlike the one outlined by Peek,* although the introduction of some new details has been made therein which add much valuable data to the tests and possibly permit of greater accuracy in the final results.

The secondary of a 300,000-volt, 30-kw., 60-cycle transformer, previously constructed at the University, was opened at the grounded neutral and a Rowland dynamometer, calibrated as an ammeter, and one of the elements of an oscillograph were connected in series therewith. See Fig. 2. As the dynamometer had been previously calibrated with a potentiometer and standard cell, the effective value of the current wave obtained by means of the oscillograph was accurately known. An auxiliary coil having a diameter equal to that of an average secondary coil and so placed as to link the average flux cutting the secondary coils was connected in parallel with a voltmeter and a second oscillograph element. The middle point of the auxiliary coil was grounded. A spark gap was introduced into the secondary circuit, see Fig. 2, to protect against excessive voltage in case the latter should be accidentally opened. These ground connections together with those upon the magnetic circuit and frame of the oscillograph eliminated effects due to static charges which might have otherwise affected the calibration or reading of the instruments. The ratio of turns on the auxiliary and secondary windings was not depended upon to determine the secondary voltage but a calibration curve was plotted between auxiliary coil voltage and secondary voltage as determined

*See paper by F. W. Peek, Jr., A.I.E.E. Proceedings, July, 1911.



[HARDING]

Fig. 1

by spark gap measurement under all conditions of transformer loading and line spacing (See Figs. 3 and 4). The ordinate of the oscillograph voltage wave was therefore expressed in terms of secondary voltage between wires while the current and voltage readings and waves combined enabled the power factor, power and wave distortion to be determined. As a check, readings in the primary were also taken.

The line spacing having been carefully adjusted, the calibration of the auxiliary coil voltage in terms of both spark gap distance (Fig. 3) and actual kilovolts taken from the A.I.E.E.

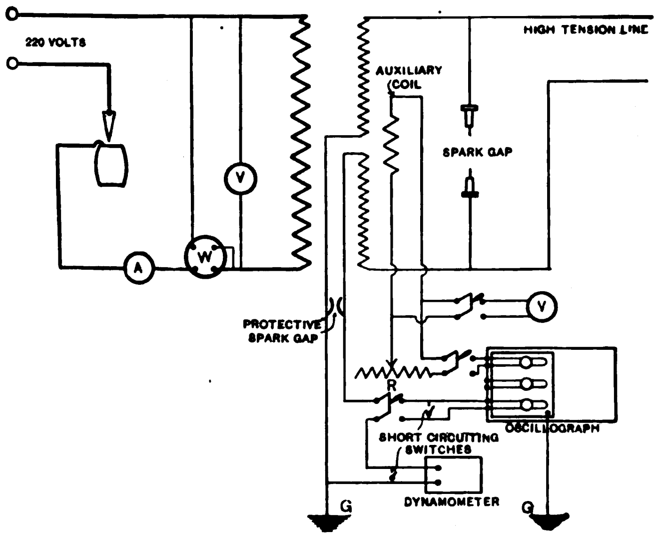


FIG. 2

standard spark gap curve was determined (Fig. 4) first with the line and feeders and secondly with the rack and feeders connected to the transformer. The difference between these two calibration curves, Fig. 4, due to the greater leakage flux in the transformer when furnishing the greater charging current demanded by the line, is quite marked and may have introduced errors in other investigations even when a portion of the secondary winding was used as an auxiliary exploring coil, if the above calibration with the secondary line spark gap was neglected.

With this information at hand eight or nine desirable voltages were selected for the test and after the amplitude of the waves

of voltage and current had been carefully adjusted upon the oscillograph screen by varying oscillograph field excitation, suspension tension and galvanometer circuit resistance in the case of the voltage wave, a film was exposed at each voltage to obtain a single point on the loss curve. By displacing the zero line somewhat the two wave forms at a single voltage with and with-

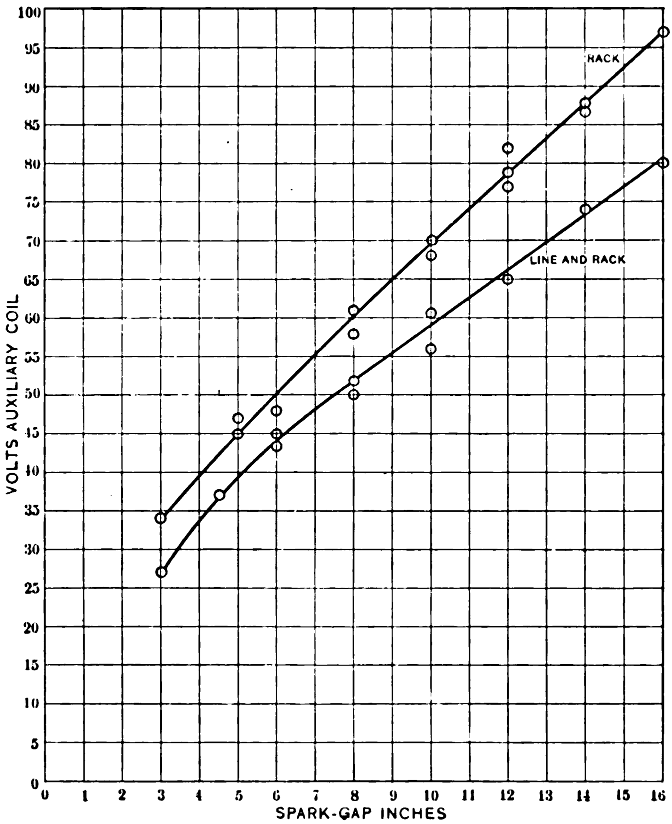
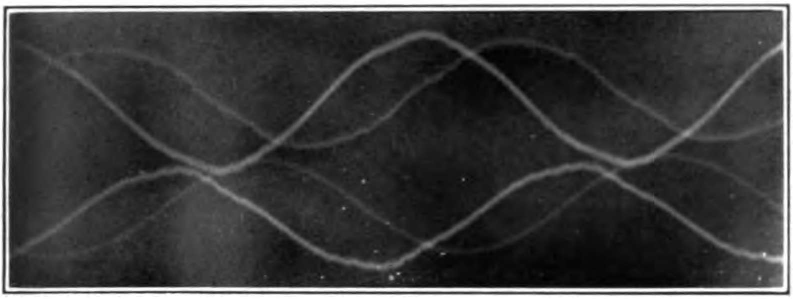


FIG. 3.—CALIBRATION CURVE—AUXILIARY COIL AND SPARK GAP. No. 4 wire, 6-ft. spacing.

out the rack could be exposed upon a single film. Such a record is illustrated in Fig. 5. At the instant the film was exposed readings of secondary current and auxiliary coil voltage, the latter being held constant during the test, were taken together with primary voltage, current and power. To provide against a failure in exposure a tracing was also made of the wave



[HARDING]

FIG. 5

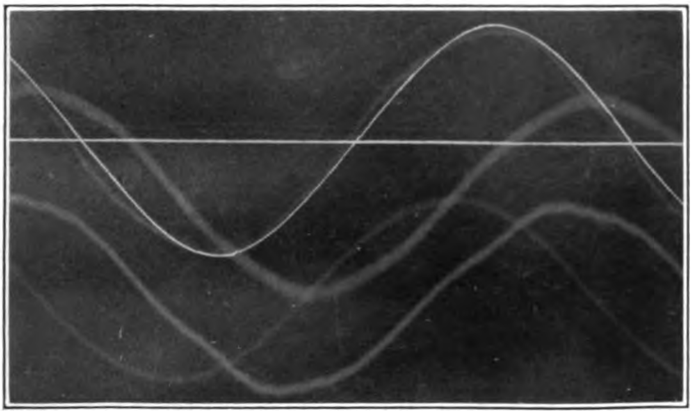


FIG. 6 [HARDING]

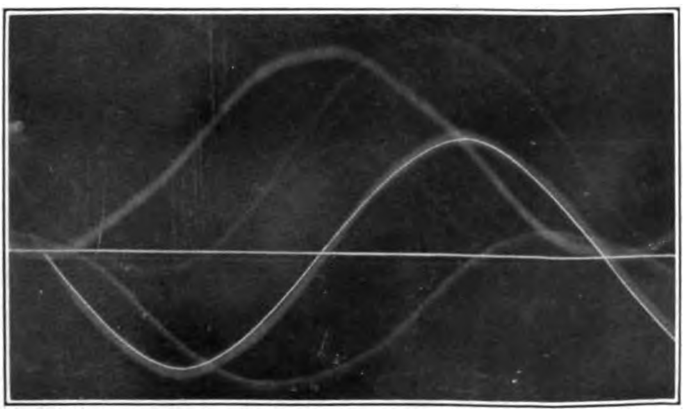


FIG. 7 [HARDING]

forms as they appeared upon the screen, but these tracings were used in but two points among all the curves obtained.

As wave distortion, if present, would require the calculation of an equivalent sine wave in order to make this method dependable, a careful study was made of the wave shapes obtained for

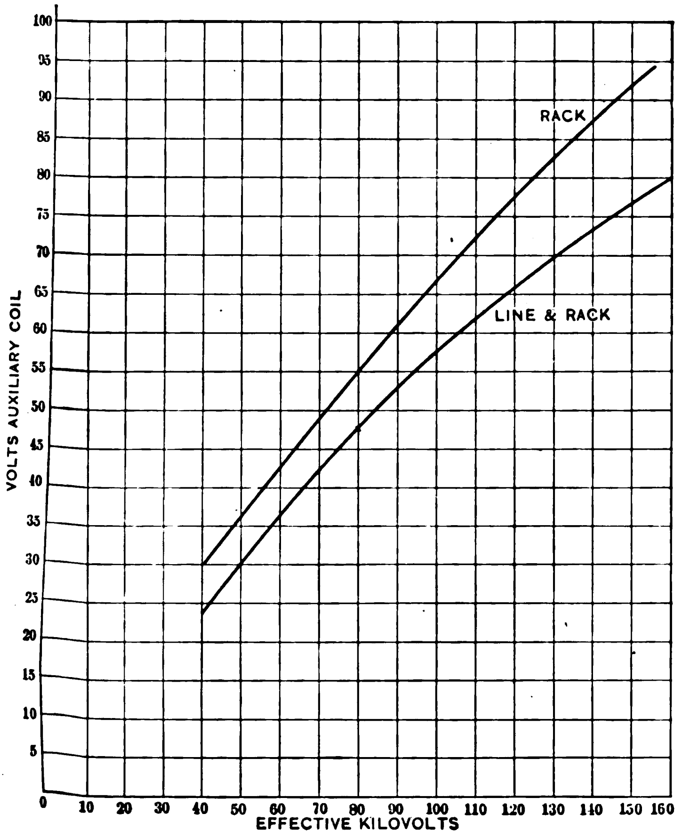


FIG. 4.—CALIBRATION CURVE—AUXILIARY COIL READING AND SECONDARY EFFECTIVE KILOVOLTS.

No. 4 wire—6 ft. spacing.

both voltage and current. Only at very low values of line voltage was any effective distortion noticeable and the error thereby produced is seen by Fig. 6 to be small and located upon a portion of the loss curve where it is of little consequence. No calculations were therefore made of the equivalent sine wave except to determine Fig. 6. In Fig. 7 will be seen a comparison between

a mathematically calculated sine wave and the actual wave obtained from the line test.

The zero line produced by the oscillograph was not depended upon, but the mean of the maximum deflections of the waves was used for drawing an accurate zero line upon the film. This line as well as the displacements of the points of zero voltage and current were very accurately determined by placing the developed film over a sheet of section paper with the peaks of the waves tangent to a given section line and noting the section

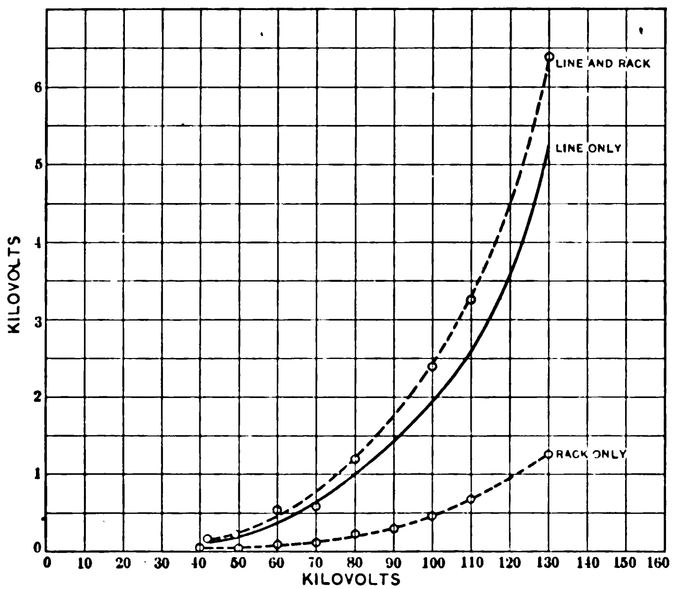


Fig. 8.—Atmospheric Loss—1000-ft. Line.

No. 4 wire—6-ft. spacing—60 cycles—barometer 29.62 in.—temperature 41 deg. fahr.—humidity 63 per cent.

line upon which the waves cut the zero line. The ratio of the average wave displacement thus measured to the average length of film required for a half cycle represented the ratio of displacement angle to 180 deg. The cosine of this angle was taken as the power factor.

Results

Curves showing the relation between corona loss and voltage between wires for No. 4 B. & S. solid copper clad steel wires are shown in Figs. 8, 9 and 10, the broken lines indicating test

results and the full line the actual loss upon the line proper after deducting losses on insulator rack and feeders. Fig. 10 also shows the increase of power factor with increase of voltage, indicating a rather marked change in slope beyond the critical voltage. Later tests indicated that the loss over the insulators was negligible and that the lower loss curve was made up principally of feeder losses. All losses were reduced to a standard length of line (two wires in parallel) of 1000 ft.

In order that a further study of these curves might be made the

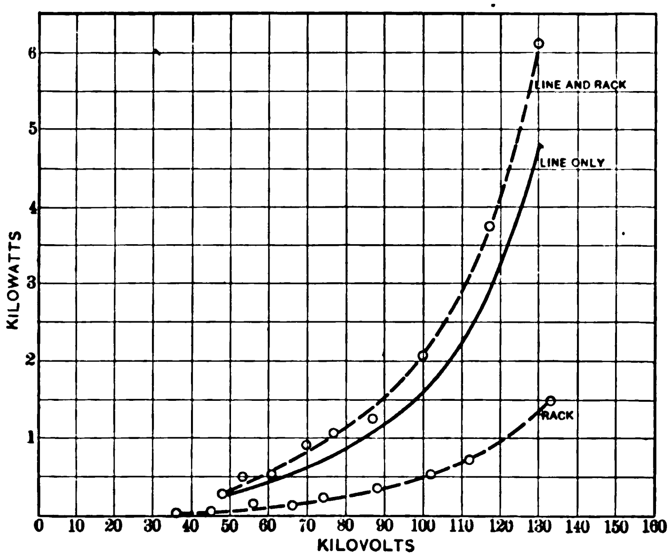


FIG. 9.—ATMOSPHERIC LOSS—1000-FT LINE.
No. 4 wire—8-ft. spacing—60 cycles—barometer 29.4 in.—temperature 56.5 deg. fahr.—humidity 69 per cent.

square roots of their kilowatt values (ordinates) were plotted in Fig. 11 against kilovolts as abscissas. It is evident that they obey the quadratic law both above and below the visual critical voltage, e_v, although the slope is different above that value, as would be expected. It is a significant fact that while the points thus plotted from the net loss curves of Figs. 8, 9 and 10, respectively, fall very accurately upon straight lines, none of the other curves involving more or less than the net losses between wires obey such a law. This seems to indicate that the method used is an accurate one.

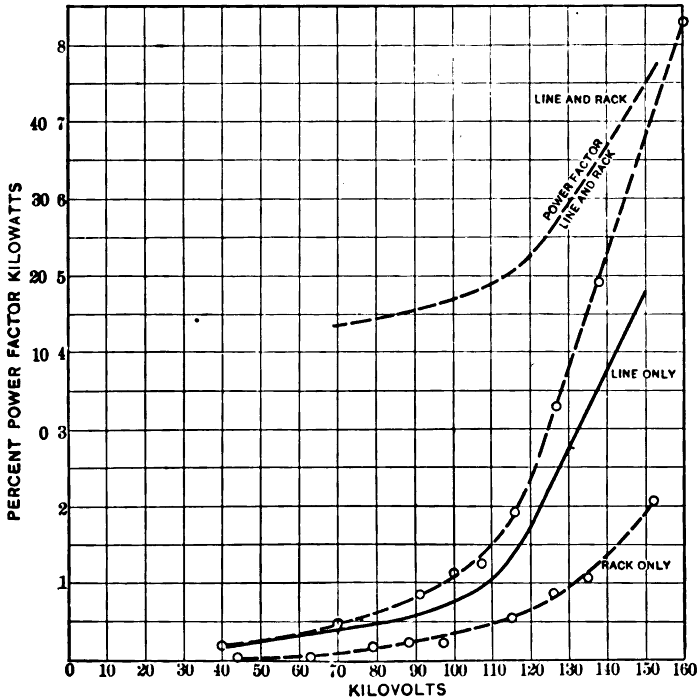


FIG. 10.—ATMOSPHERIC LOSS—1000-FT. LINE.

No. 4 wire—10-ft. spacing—60 cycles—barometer 29.36 in.—temperature 49 deg. fahr.—humidity 86 per cent.

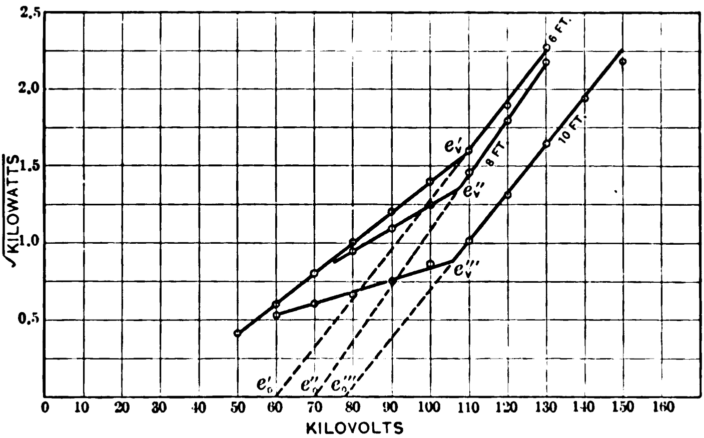


FIG. 11.—ATMOSPHERIC LOSS—QUADRATIC ANALYSIS.

100-ft. line—No. 4 wire—6, 8 and 10 ft. spacings—60 cycles.

The application of the Σ Δ method to these curves results as follows.

TABLE I

Spacing	Critical disruptive voltage	Equation of curve	
		Below visual critical voltage	Above visual critical voltage
6 ft.	59.3	$kw = 0.00158\,(e - 14.9)^2$	$kw = 0.00404\,(e - 29.7)^2$
8 "	69.3	$kw = 0.00086\,(e - 7.5)^2$	$kw = 0.00512\,(e - 34.7)^2$
10 "	77.5	$kw = 0.00022\,(e + 6.45)^2$	$kw = 0.00388\,(e - 38.8)^2$

The accuracy with which these equations represent the experimental curves may be noted in Fig. 12 where the full line

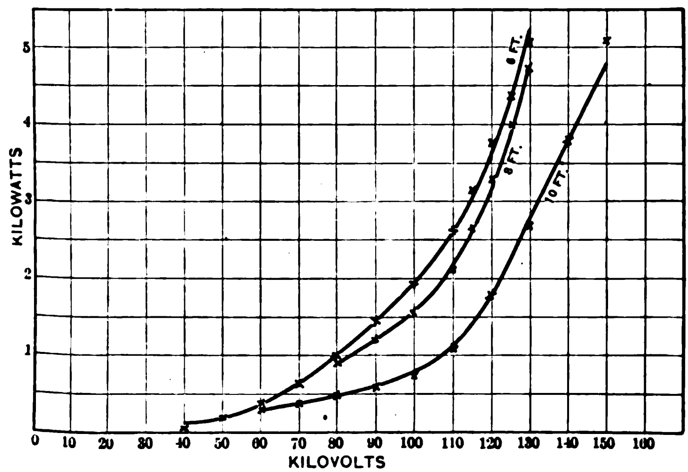


FIG. 12.—ATMOSPHERIC LOSS—1000-FT LINE.
No. 4 wire—60 cycles.

curves are taken from Figs. 8, 9 and 10 and the crosses indicate the points calculated by means of the above equations.

A further check upon the formulas which have been proposed to determine corona loss* will be found below.

Let e_0 = effective disruptive critical voltage to neutral.
m_0 = constant depending upon condition of surface of wires = 0.93 for solid weathered wires.
g_0 = disruptive gradient of air = 21.1 kv. per cm. effective.
δ = air density factor.
r = radius of wire in cm.
s = distance between wire centers in cm.

*See paper by F. W. Peek, Jr., A. I. E. E. PROCEEDINGS, July, 1911.

whence

$$e_0 = m_0\, g_0\, \delta\, r \log_e \frac{s}{r}$$

Applying this formula to the test at the 10-ft. spacing, Fig. 10,

$$\delta = \frac{17.91 \times 29.36}{459 + 49} = 1.036$$

$$r = 0.259 \text{ cm.}$$

$$s = 305 \text{ cm.}$$

$$e_0 = 0.93 \times 21.1 \times 1.036 \times 0.259 \log_e \frac{305}{0.259} = 36.6 \text{ kv.}$$

e'_0 (between wires) = 73.2

e'_0 (from curve) = 77.5 kv.

The following table compares the values of effective disruptive critical voltage (e_0) calculated from the other tests by means of the above formula, and the empirical values determined from the curves.

TABLE II

Wire spacing	e_0 – calculated	e_0 – from curve
6 ft.	68.8 kv.	59.3 kv.
8 "	71.2 kv.	69.3 kv.
10 "	73.2 kv.	77.5 kv.

Although there is considerable departure from the calculated value in the test at six-ft. spacing, the tests at wider spacings check remarkably well when it is considered that the tests were carried on in an entirely different locality and under different conditions of temperature and pressure than those upon which the formulas were based.

But the comparison may be carried still further and the corona loss calculated from Peek's formula.

Let p = corona loss in kw.
k = constant = 344 in original formula.
f = frequency in cycles per second.

$$p = \frac{k}{\delta} f \sqrt{\frac{r}{s}}\, (e - e_0)^2\, 10^{-5} \text{ kw. per km. per wire}$$

$$\text{or } p' = 0.0021 \frac{f}{\delta} \sqrt{\frac{r}{s}}\, (e - e_0)^2 \text{ kw. per 1000 ft. for two wires.}$$

Again considering the ten-foot spacing

$$p' = \frac{0.0021 \times 60}{1.036} \sqrt{\frac{0.259}{305}} \, (e - e_0)^2$$

$$= 0.00355 (e - 38.8)^2$$

if the value of (e_0) be taken from the test, or

$$p' = 0.00355 \ (e - 36.6)^2$$

if the calculated effective disruptive critical voltage be used.

The curves resulting from the calculations thus outlined may

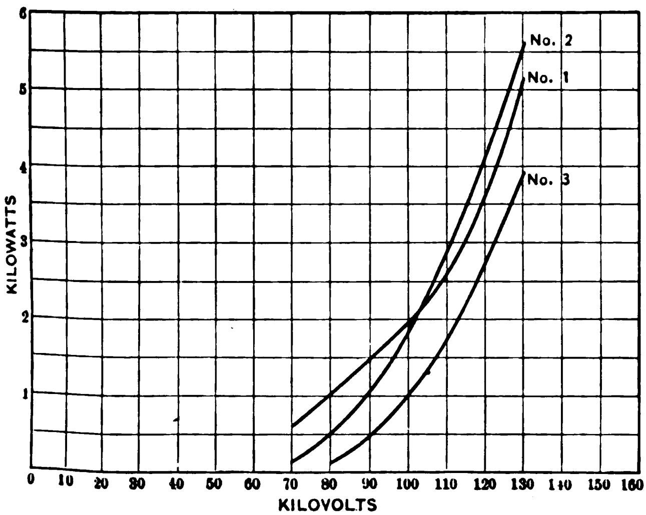


FIG. 13.—ATMOSPHERIC LOSS—1000 FT LINE.
6-ft. spacing—No. 4 wire—60 cycles.
No. 1—Results of test.
No. 2—Calculated, e_0 from test.
No. 3—Calculated, e_0 (Peek's formula).

be compared with the experimental values in Figs. 13, 14 and 15, where it will be seen that the three curves fall remarkably close to one another above the visual critical voltage and especially at the 10-foot spacing, indicating that the calculated values are sufficiently accurate for any practical transmission line design.

OTHER TESTS COMPARED

It is a significant fact that the corona loss curves resulting from the tests outlined in this paper obey a quadratic law both below and above the visual critical voltage, although the constant

is different for the two portions of the curve. Peek's curve below the visual critical voltage was represented by a more complicated equation than the quadratic. A study of the results of other observers indicates that only an occasional curve obeys the quadratic law. For instance, but four of the twenty-nine curves determined by Mershon* are quadratic and these four, Figs. 14 and 15, represent tests upon very large stranded cables at comparatively low voltages so that but little of the curve above the critical voltage is available. The corona losses upon the Shoshone-Denver lines of the Central Colorado Power Com-

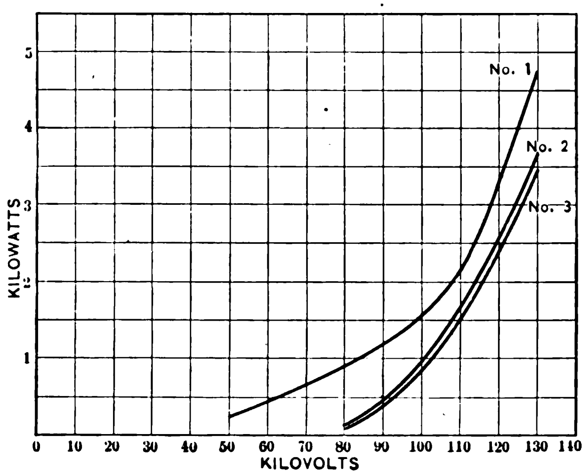


FIG. 14.—ATMOSPHERIC LOSS. 1000-FT. LINE.

8-ft. spacing—No. 4 wire—60 cycles.

No. 1—Results of test.
No. 2—Calculated, e_0 from test.
No. 3—Calculated, e_0 (Peek's formula).

pany were found by Faccioli† to obey the quadratic law. The three groups of tests reported by Peek, Faccioli and the present paper not only offer an interesting comparison between results upon actual and experimental transmission lines but, following as they do the quadratic law, the latter seems to have been fully established as the correct law of corona, especially as the tests mentioned were determined by measurements taken directly in the high-tension line under investigation and not in the primary circuit.

*See paper by R. D. Mershon, A. I. E. E. TRANSACTIONS, Vol. XXVII.
†See paper by G. Faccioli, A. I. E. E. TRANSACTIONS, Vol. XXX.

In Fig. 16 will be found a comparison of the results of several tests upon both operating and experimental transmission lines in which the losses have been reduced to a standard length of 1000 feet of two-wire line. Curves 1, 2 and 3, having nearly the same size of wire and spacing may be compared with one another. Such comparison indicates that Mershon's results are considerably lower than the others while those of this paper check Peek's results fairly well, especially at the higher voltages. A similar study of curves 4, 5 and 6, which represent very similar

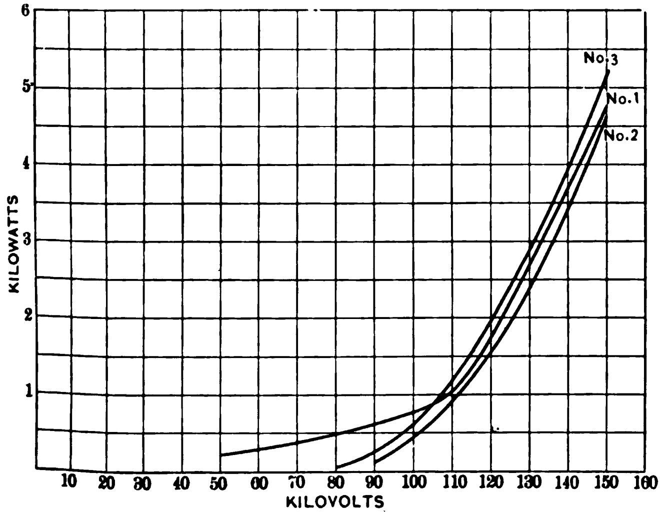


Fig. 15.—Atmospheric Loss—1000-ft. Line.

10-ft. spacing—No. 4 wire—60 cycles.

No. 1—Results of test.
No. 2—Calculated, e_0 from test.
No. 3—Calculated, e_0 (Peek's formula).

line conditions, indicates that Peek's equation gives too low values of loss. This lower loss indicated by the curve resulting from Peek's equation as compared with test results upon operating lines seems to confirm the inference which might have been made from Figs. 13, 14 and 15 that values calculated from Peek's equation are slightly too low. The number of tests available does not justify a change in the equation, however.

The use of copper clad steel wire in these tests has already been mentioned. It may be of interest to note that the conductivity of this line was 43 per cent of that of a copper line of the same gage and that the impedance with the eight-ft. spacing

was found to be 1.75 ohms or 0.634 ohms per 1000 ft. of wire. The impedance of a No. 4 B. & S. copper line with the same spacing is found to be 0.82 ohms or 46.9 per cent of the copper clad line. With the higher voltages, longer spans and corona loss limitations, however, the increase in impedance may prove

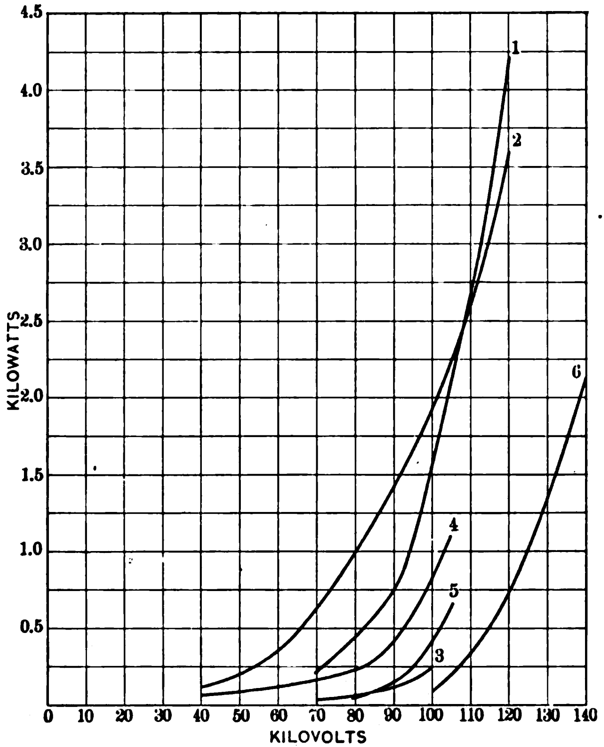


FIG. 16.—ATMOSPHERIC LOSS—1000-FT. LINE.

Curve	Authority	Size wire	Spacing
1	Peek (test)	No. 8	6 ft.
2	Harding	No. 4	6 ft.
3	Mershon	No. 4 str.	7 ft.
4	West	1/0 and 1	10 ft. 4½ in.
5	Faccioli	1/0	10 ft. 4½ in.
6	Peek (calc.)	1/0	10 ft.

to be a negligible factor and the increased tensile strength found to be available for high-tension line construction.

CONCLUSIONS

1. Corona loss may be readily and accurately determined with instruments connected directly into the high-tension circuit.

2. The use of the oscillograph for this purpose is entirely satisfactory and furnishes many valuable data in regard to wave distortion and phase displacement not available by other methods.

3. The oscillograph may be accurately calibrated and films measured sufficiently close to guarantee dependable results.

4. When an auxiliary coil upon the step-up transformer is used, and probably in the case of the use of a section of the secondary winding to determine secondary voltage, it is necessary to calibrate such a coil with the secondary voltage for the various possible conditions of load and power factor.

5. Corona loss curves are parabolas, the constants of the equations being different above and below the visual critical voltage.

6. The equations of corona loss curves may be very closely approximated by means of the $\Sigma \Delta$ method.

7. Test values checked results calculated from Peek's formula for points above the visual critical voltage with a fair degree of accuracy, especially at the wider spacings between wires.

8. Variations from Peek's formula were in the direction of greater losses for a given voltage than those given by the formula. This was also found to be true of the tests which have been made upon operating lines, when the latter were reduced to a common standard for comparison.

The writer wishes to express his appreciation of the assistance rendered by Messrs. Phelps and Curtner, graduate students at the University, and to Messrs. Cox and Burke, who aided in the design and construction of the line and in taking readings. Recognition is also hereby expressed for the cooperation of the Locke Insulator Co., the Franklin Steel Co. and the Duplex Metals Co. which enabled these tests to be successfully carried out.

A paper presented at the 29th Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June 28, 1912.

DETERMINATION OF POWER EFFICIENCY OF ROTATING ELECTRIC MACHINES

Summation of Losses Versus Input-Output Tests

BY E. M. OLIN

Recently there has been a considerable movement on the part of several large buyers of electrical apparatus to the end that efficiency tests of rotating apparatus be made by input-output measurement rather than by the summation of separate losses. One of the engineering societies* has also lent its approval to this movement.

Paragraph 92 of the Standardization Rules of this Institute, headed " Comparison of Methods " (for the determination of efficiency) states " The output and input method is preferable with small machines. When, however, as in the case of large machines, it is impracticable to measure the output and input, or when the percentage of power loss is small and the efficiency is nearly unity, the method of determining efficiency by measuring the losses should be followed."

The terms " small machines " and " large machines " in this paragraph are indefinite and unsatisfactory. The purpose of this paper is to discuss both methods and from a consideration of certain data to show that efficiencies can be satisfactorily computed from no-load losses in all cases provided empirical correcting factors are used therewith to compensate for load losses, and that efficiencies so calculated will in general be much nearer the true values than those made by the average input-output test.

It is well known that certain of the losses occurring in elec-

*National Electric Light Association.

trical machines can be accurately determined from no-load measurements. Some of the losses, however, cannot be so determined, as, owing to conditions which develop, as load is applied a gradual increase in these losses takes place.

The difference between the total losses under load and the sum of the separate losses as determined from no-load measurements is commonly known as " load loss."

It is proposed by the writer to indicate a method which will establish the ratio of this load loss to the losses indicated by the no-load measurements. This ratio will vary for different types of apparatus.

Briefly stated the method proposed is as follows:

From a series of reliable input-output tests derive the actual losses of a large number of machines of varying types and sizes.

Determine the losses of these same machines by the summation of loss method without increasing the separate losses to allow for field distortion or other load factors.

The difference in the losses as found by the two methods will be the so called *load loss*.

Having determined the magnitude of this load loss for different types and sizes of apparatus, derive multiplying constants which can be applied to the separate loss values to obtain their true values under load.

It is highly desirable to use the separate loss measurements for computing efficiency for the following reasons:

The necessary tests are simple and require but few observers. For that reason they can be easily and accurately taken.

On the other hand the input-output test is complicated and if the desired accuracy is to be obtained it must be carried on with all the safeguards and refinements employed in the most delicate laboratory work. For that reason only the most expert operators can be used. A large number of simultaneous readings are required and the errors of observation are likely to be additive. Experience has shown that repeated tests must be made before consistent results are obtained.

According to the Standardization Rules of this Institute (paragraphs 7 to 21) the term " Rotating Machines " includes:

a. Direct-current generators
b. Alternators
c. Double-current generators
d. Induction generators
e. Boosters

f. Direct-current motors
g. Alternating-current motors
h. Synchronous condensers
i. Motor-generators
j. Dynamotors

k. Converters	Direct-current converters
	Synchronous converters (rotaries)
	Motor converters
	Frequency changers
	Rotary phase converters

(a) (b) (c) (d) and (e) may be driven by prime movers or by motors. When motor driven they are included under class (i).

The most ardent advocate of the input-output test would hardly recommend this method for generators driven by prime movers, involving as it would the determination of mechanical power delivered at the shaft of the generator, so we can at once dismiss the first five items from our consideration.

The power efficiency of the synchronous condenser running idle is nil and when running under load this type falls under (g) so that we need not consider it in a special class.

There remain then for our attention the following:

1. Motors.
2. Motor-generators.
3. Dynamotors.
4. Converters.

1. *Motors.* The efficiency of motors may be determined by measuring the losses and subtracting them from the input to derive the output or by measuring the input and output directly. In the latter case the mechanical output is measured by some form of brake or other dynamometer.

2. *Motor-Generators;* 3. *Dynamotors;* 4. *Converters.* The efficiency of a motor-generator, dynamotor or converter may be determined by measuring the losses and adding them to the output to derive the input, or by measuring the input and output directly. In the latter case simultaneous readings of the electrical input and output are taken with suitable measuring instruments.

The losses which take place in rotating electrical apparatus are well known. Briefly stated they are:

Frictional losses	of shafts with bearings
	of brushes with commutators
	of brushes with collector rings
	of rotating element with air (windage)

I^2r losses
- a. Due to the resistance of windings, brushes and sliding contacts to useful current flowing in the apparatus.
- b. Due to the resistance of any part of the apparatus to non-useful current. These losses include the following:
  Losses due to eddy currents in the copper conductors, laminations, pole faces, damper windings and other metallic parts.
  Losses in armature coils and commutator leads which are short circuited by the brushes.
  I^2r losses in multiple circuit windings

Hysteresis or molecular magnetic friction.

To derive efficiency by the separate loss method it is necessary:

1. To determine the resistance of windings, brushes and sliding contacts at a known temperature.

2. To determine the regulation with reference to speed, voltage, and current flowing in the various windings.

3. To determine the frictional losses over the range of speed indicated by the regulation.

4. To determine the "rotation loss" (commonly known as the "core loss.") This loss includes hysteresis, the eddy current losses in iron, copper and other metallic parts, I^2r losses in cross connections and I^2r losses in armature coils and amature leads which are short circuited by the brushes as far as these losses are due to rotation.

5. To determine the eddy current losses in the iron and especially in the copper conductors so far as these losses are due to stray fields set up by useful currents flowing in the windings.

6. To determine the alternating or transformer loss. This loss occurs only in machines whose field windings are excited with alternating current, as in the case of a-c. commutator motors. It includes hysteresis and eddy current losses due to the alternation of the magnetic field, I^2r losses in cross connections of armatures and I^2r losses in armature coils and commutator leads which are short circuited by the brushes as far as these losses are due to the alternation of the magnetic field.

1. *Resistances.* The resistances of windings can be measured with the greatest accuracy by several well known methods, which need not be discussed here.

The resistance of brushes and sliding contacts can also be determined with precision. The method is as follows: Current of normal characteristics from an external source is sent through

the brushes and sliding contacts while operating at normal speed, the fall of potential indicating the resistance. A commutator or set of collector rings, for example, is assembled for rotation with its brush holder and brushes but without connections to the armature windings. In the case of the commutator the bars are short circuited by band wires at the ends. The apparatus is then driven at normal speed and the brush holders placed in series with current of normal characteristics from an external source. The fall of potential across the brush holders indicates the resistance of brushes and sliding contacts. Such tests have been made repeatedly by various engineers and the values for different grades of carbon or copper brushes with varying speed and brush densities have been accurately determined. So that in computing the loss due to the resistance of brushes and sliding contacts it is usual to refer to data already compiled rather than to actually measure the resistance in each particular case.

2. *Regulation.* What constitutes regulation is defined in paragraphs 187-203 of the Standardization Rules and the *conditions for and tests of regulation* are covered by paragraphs 204-209.

It is necessary to determine over the entire range of load, (A) speed, (B) voltage, (C) current flowing in the windings.

The apparatus should be operated under normal conditions if possible, but when, as in the case of large machines, it is impracticable to make actual load tests the regulation can be approximately determined from data taken at no-load. Such regulations are sufficiently accurate for efficiency determination by the summation of loss method.

3. *Frictional Losses.* Losses due to mechanical friction, including windage, are independent of the load. The most satisfactory method for measuring these losses is by separate drive from an independent motor, preferably of the direct-current, commutating pole type. The apparatus is driven at normal speed on open circuit without current in any winding. When so operating, the input to the driving motor is greater than its own no-load losses by an amount equal to the frictional losses of the driven apparatus plus a small increase due to load loss in the driving motor itself. This load loss is composed as follows:

a. The increased I^2r loss in the armature circuit.

b. The increased rotation loss due to field distortion.

c. Eddy current losses caused by the stray fields of useful currents in the armature circuit.

a. Can be computed by a simple calculation involving the known current flowing and the resistance of the armature circuit, (copper conductors, brushes and sliding contacts).

b. Cannot be satisfactorily determined by the separate loss method as will be pointed out under " Rotation Loss." It is usually disregarded in figuring the increased power input to the driving motor.

c. Is usually so small in motors of this type that it can be ignored. In fact it is customary to ignore (a) (b) and (c) in measuring frictional and rotation losses. It is to be noted, however, that the error introduced by so doing lowers the calculated efficiency, since the loss is incorrectly charged to the driven apparatus instead of to the driving motor.

To determine the frictional loss at a given speed it follows that two power input readings to the driving motor are necessary, one when driving the apparatus and the other when running free at the same armature voltage and speed.

4. *Rotation Loss.* In determining the rotation loss of induction motors the apparatus is operated at no-load and normal voltage, the power input under these conditions being the sum of the frictional losses and the rotation loss. The rotation loss can then be segregated by subtracting from this result the frictional loss as determined above.

In all other rotating apparatus the rotation loss is best measured on open circuit by the separate drive method in a manner similar to that described under " Frictional Losses."

The power input to the driving motor is noted with the fields of the driven apparatus charged, and with the fields uncharged, the difference in the input, when corrected for the driving motor loss, being the " rotation loss."

This loss is composed of two parts:

m. Hysteresis and eddy current losses caused by rotation through the magnetic field.

n. I^2r losses in cross connections of armature.
I^2r losses in armature coils and armature leads which are short circuited by the brushes.
I^2r losses which may exist in multiple circuit windings.

That part of the " rotation loss " due to hysteresis and eddy currents will increase somewhat under actual load conditions over its value at no-load as measured above. This increase is due

to field distortion and may be a considerable percentage of the value measured at no-load.

There is no satisfactory method of computing from no-load readings the increased rotation loss due to field distortion under load.

The I^2r losses in cross connections of armatures and the I^2r losses in armature coils and armature leads which are short circuited by the brushes depend upon the voltage and are independent of the load. That part of the "rotation loss" due to those factors may be assumed to be correct for all loads as measured by the separate drive method at no-load.

5. The losses in the iron, and especially in the copper conductors, due to eddy currents from stray fields set up by useful currents flowing in the windings, are often a considerable item, particularly in machines having deep slots with conductors of large cross sections.

These losses may be approximately determined in certain types of machines by operating them on short circuit at several different speeds and currents.

Paragraph 167 of the Standardization Rules described this method as applied to induction motors. Some modifications must be made however in order to obtain accurate results. This paragraph states "These losses 'load losses' may for practical purposes be determined by measuring the total power, with the rotor short circuited at standstill and a current in the primary circuit equal to the primary energy current at full load. The loss in the motor under these conditions may be assumed to be equal to the load losses plus I^2r losses in both primary and secondary coils."

It is to be noted that with the rotor at standstill and current of normal characteristics flowing in the primary, the frequency of the secondary current is the same as that of the primary. In practise, however, the frequency of the secondary (which is proportional to the slip) is very low. Therefore the losses due to eddies in the secondary conductors will be greatly magnified during the above test because of the high frequency.

To approximate these losses more nearly a series of readings should be taken with currents of varying frequency in the primary windings. This varying frequency should be brought down to as low a value as practicable. A comparison of the values thus obtained will indicate the losses under normal conditions.

The power input during these tests will of course include the ordinary I^2r losses of primary and secondary windings. These must be subtracted from the total input readings to arrive at the loss due to eddies.

There is no satisfactory no-load method of measuring this eddy current loss in the case of direct-current motors and generators and in alternating-current machines of the synchronous type. When operating such machines on short circuit so many other losses occur that it is practically impossible to segregate the eddy current loss due to the stray fields set up by currents flowing in the windings.

6. The alternating or transformer loss is measured simultaneously with the "rotation loss" by noting the power consumed by a wattmeter connected across the field circuit. A wattmeter so connected will measure

a. The I^2r loss of the field windings.

b. The I^2r loss of armature coils and commutator leads which are short circuited by the brushes as far as these losses are due to the alternation of the magnetic field.

c. Hysteresis and eddy current losses due to the alternation of the magnetic field.

> a. Can be computed from the measured resistance and known current flowing.
>
> b. Can be separated from the other losses by running the machine with and without brushes on the commutator.
>
> c. Is the difference between the total watts and the sum of (a) and (b).

The alternating or transformer loss is equal to the sum of (b) and (c).*

This loss is a function of the alternating current in the field windings and for any given current will be the same whether the motor is doing work or is running free, driven from a separate motor.

The general expressions for calculating efficiency by the *Summation of Loss Method* are as follows:

*An exception is to be noted in alternating-current commutating motors where commutating compensation is obtained by the use of a cross field. Under this condition a portion of the loss ordinarily supplied by the alternating-current exciting current will be furnished by the driving motor.

For Motors Efficiency $= \dfrac{\text{Input} - \text{Losses}}{\text{Input}}$

For $\left\{\begin{array}{l}\text{Motor-Generators}\\ \text{Dynamotors}\\ \text{Converters}\end{array}\right.$ Efficiency $= \dfrac{\text{Output}}{\text{Output} + \text{Losses}}$

$$\text{Losses} = W_{I^2R} + W_F + W_R + W_E + W_T$$

Where W_{I^2R} = Watts lost due to the resistance of windings, brushes and sliding contacts to useful current flowing.

W_F = Watts lost in friction.

W_R = Rotation loss.

W_E = Watts lost due to eddy currents in iron and especially in copper conductors caused by the stray field of useful currents flowing in the windings.

W_T = Transformer or alternating loss.

Before proceeding further we will examine some data relating to the separate losses of rotating apparatus as compared with the rated output. The no-load values of W_R are given in these data. No values of W_E are shown as this loss was not investigated in the case of machines given in these lists.

Apparatus	Description	Rating		Per cent of rated output				
		Output h.p.	Frequency cycles	W_{I^2R}	W_F	W_R	W_T	Total losses
Direct-current motors	Commutating pole	25		8.9	1.77	1.65		12.32
		35		6.25	1.95	2.74		10.94
		40		5.5	2.48	2.40		10.38
		50		4.65	1.87	2.08		8.6
		60		5.24	1.80	1.7		8.74
		75		6.1	1.64	1.64		9.38
		75		4.1	1.60	1.78		7.48
		75		6	1.02	1.81		8.83
		100		7.15	1.04	1.15		9.34
		250		6.95	0.61	0.96		8.52
		270		7.55	0.69	0.72		8.96
		300		3.92	0.89	2.41		7.22

Apparatus	Description	Rating		Per cent of rated output				
		Output h.p.	Frequency cycles	W_{I^2R}	W_F	W_R	W_T	Total losses
Direct-current motors	Non-commutating pole	6		13.2	2.07	3.46		18.7
		90		11.3	2.38	0.95		14.68
		400		4.6	0.93	3.74		9.27
Synchronous motors		290	60	1.47	1.94	2.43		5.84
		720	25	1.89	1.73	3.79		7.41
		1080	25	1.29	1.25	1.99		4.53
		2860	50	1.65	1.28	1.90		4.83
		3000	60	0.70	0.73	2.73		4.16
Alternating-commutator motor	Series type	150		7.6	3.18	2.39	3.16	16.33
		315		5.3	2.77	2.2	3.42	13.69
Induction motors	Wound secondary	7½	60	10	4.28	4		14.28
		50	60	3.6	3.22	3.63		10.45
		75	60	5.95	2.14	2.02		10.11
		150	60	2.19	1.87	2.38		6.44
		200	60	6.34	1.68	2.69		10.71
		350	60	5.4	1.46	2.3		9.16
		500	60	3.77	1.66	2.06		7.49
		1200	60	1.42	1.79	1.67		4.88
		3000	25	5.2	0.90	1.52		7.62
		11	60	10.3	1.71	6.23		18.24
		18	60	9.26	1.87	6.13		17.26
		25	60	4.55	1.88	5.42		11.85
		35		5.15	1.53	9.25		15.93
		75	60	3.85	1.34	5.8		10.99
		100	25	9	2.28	6.3		17.58
		125	60	10.5	1.29	5.15		16.94
		225	60	6.85	0.65	3.1		10.6
Induction motors	Cage secondary	5	60	10.82	2.28	4.5		17.6
		20	50/60	4.07	2.35	4.56		10.98
		20		11.35	2.15	3.39		16.9
		40	50	4.82	1.68	6.22		12.72
		20	60	3.46	1.47	3.55		8.48
		50	60	3.73	0.59	1.96		6.28
		50	25	3.35	0.86	2.76		6.97
		75	25	3.74	0.82	1.5		6.06
		150	60	1.90	2.32	3.22		7.44
		2	60	8.58	4.02	4.5		17.1
		5	60	4.22	6.3	2.98		13.5
		20	60	5.3	1.61	3.17		10.08
		30	60	2.37	5.35	1.45		9.17
		40	25	6.1	2.68	2.01		10.79
		100	60	2.07	1.72	1.96		5.75
		125	60	1.92	2.57	2.25		6.74
		200	25	4.71	0.87	2.69		7.5
		300	60	5.06	1.7	1.9		8.66
		450	60	4.08	1.67	2.91		8.66
		750	25	4.9	0.72	3.03		8.65

Apparatus	Description	Rating		Per cent of rated output			
		Output kw.	Frequency cycles	W_{I^2R}	W_F	W_R	Total losses
Direct-current generators	Commutating pole	20		5.15	6.03	3.6	14.78
		75		6.29	1.53	2.4	10.22
		100		4.86	1.49	2.15	8.50
		150		3.72	3.24	2.13	9.09
		150		3.75	3.04	3	9.79
		150		4.85	2.90	1.8	9.55
		175		5.51	1.28	4.45	11.24
		200		3.99	2.25	2.14	8.38
		200		4.03	2.25	1.61	7.89
		200		5.10	1.95	2.62	9.67
		200		4.24	1.92	2.80	8.96
		200		3.37	2.37	1.62	7.36
		250		4.85	4	1.45	10.3
		250		4.17	1.7	1.82	7.69
		300		3.49	2.89	2.43	8.81
		300		3.58	2.27	1.32	7.17
		300		3.29	1.28	1.9	6.47
		400		2.85	2.11	1	5.96
		400		3.84	2.8	1.65	8.29
		500		2.57	1.73	2.08	6.38
		500		3.5	1.65	1.88	7.03
		600		2.88	1.97	1.5	6.35
		750		3.21	1.2	2.33	6.74
		750		3.71	2.07	2.54	8.32
		1000		2.75	1	2.7	6.45
		1000		2.90	2.15	1.75	6.80
		1000		2.46	1.55	2.42	6.43
		1500		3.35	1.76	1.93	7.04
Direct-current generators	Non-commutating pole	12.5		8.2	2.64	2.84	13.68
		40		6.75	1.77	1.16	9.68
		100		6.78	0.52	1.52	8.82
		300		3.79	1.44	2.07	7.30
Alternating-current generators		100	60	2.78	1.08	3.5	7.36
		100	60	6.14	0.82	3.3	10.26
		125	60	3.19	3.70	2.97	9.86
		200	60	2.58	1.72	2.45	6.75
		300	25	1.77	0.71	3.33	5.81
		300	60	1.89	1.90	2.40	6.19
		333	60	0.83	1.47	2.94	5.24
		400	60	2.64	0.61	3	6.25
		500	25	2.25	0.50	1.42	4.17
		500	60	0.65	3.66	4.16	8.47
		600	60	0.83	1.79	2.27	4.89
		700	60	1.65	0.94	1.86	4.45
		725	60	1.52	0.70	1.27	3.49
		1000	60	1.67	1.52	1.83	5.02
		1000	60	0.74	4.10	1.66	6.50
		1250	60	1.25	0.83	2.65	4.73
		1250	60	1.04	0.83	2.59	4.46

Apparatus	Description	Rating		Per cent of rated output			
		Output kw.	Frequency cycles	W_{I^2R}	W_F	W_R	Total losses
Alternating-current generators		1500	60	0.66	3.16	3.16	6.98
		2000	60	1.03	0.92	2.10	4.05
		2000	60	1.20	1.19	1.83	4.22
		2500	60	0.56	2	2.4	4.96
		3000	60	0.95	2.01	2.46	5.42
		3000	60	0.76	1.47	2.57	4.80
		3000	25	0.51	3.73	2	6.24
		3000	60	1.18	1.62	1.70	4.50
		3750	60	1.47	0.49	1.46	3.42
		4000	60	0.47	4.13	2.53	7.13
		5000	60	0.91	0.89	1.98	3.78
		6666	60	0.41	2.17	2.55	5.13
		8000	60	0.32	2.77	2.23	5.32
		10000	60	0.40	2.40	1.85	4.65
Dynamotors		10		4.18	2.33	5.42	11.93
		9		4.01	2.23	4.84	11.08
Synchronous converters		100		2.9	2.64	3.1	8.64
		200		1.91	2.69	4.73	9.33
		300		1.93	2.05	2.27	6.25
		300		2.61	1.33	0.99	4.93
		400		2.16	0.72	2.08	4.96
		500		1.67	2.07	1.48	5.22
		500		1.59	2.23	1.50	5.32
		800		1.51	3.46	1.14	6.11
		1000		1.16	3.49	1.45	6.10
		1000		2.55	1.30	0.82	4.67
		1500		1.66	1.18	0.82	3.66
		2000		1.69	1.08	0.77	3.54
		2000		2.19	0.93	0.56	3.68
		3000		1.81	0.99	0.79	3.59
Motor-generators	*A	200		4.97	5.3	4.97	15.24
		500		5.82	4.71	5.74	16.27
		1000		4.98	4.07	3.94	12.99
		2000		4.47	2.98	3.92	11.37
Motor-generators	*B	100		11.8	3.93	5.64	21.37
		150		9.45	7.05	5.1	21.6
		300		9.06	3.59	5.4	18
		500		4.88	2.74	6.26	13.88
Motor-generators	*C	160		8.82	3.73	3.19	15.74
		300		5.57	3.58	5.28	14.43
Motor-generators	*D	94		5.95	2.68	5.83	14.46
		750		4.32	1.36	3.67	9.35
		1500		2.69	1.55	3.96	8.2

*A—Synchronous motor and direct-current generator.
*B—Induction motor and direct-current generator.
*C—Direct-current motor and direct-current generator.
*D—Frequency changer.

From these figures it will be seen that in the case of single units the total losses, as computed from separate loss measurements, vary from $3\frac{1}{2}$ to 20 per cent of the rated output, while the sum of the frictional and rotation losses ranges from 1.4 to 10 per cent. Now the measured values of the frictional and rotation losses are likely to be slightly inaccurate due to observation errors, as will be pointed out later. Since these losses are very small as compared with the total output a considerable error in the no-load readings will affect the calculated efficiency but slightly.

In the preceding paragraphs the following points have been brought out:

(1) At any given load W_{I^2R} W_F and W_T can be accurately determined from readings taken at no-load.

(2) W_R is composed of two parts, one of which (n) is constant at fixed voltage under all conditions, while the other, namely, the hysteresis and eddy current loss, increases somewhat with load.

(3) The increase in the rotation loss due to the application of load cannot be satisfactorily determined from readings taken at no-load.

(4) It is difficult, and in the majority of cases impossible, to approximate from no-load measurements the eddy current loss due to the stray field of useful currents.

Owing to the difficulty of arriving at the true value of the rotation loss under load, it is the practise of most manufacturers to specify efficiencies on the basis of the no-load values of this loss. The eddy current losses due to the stray fields of useful currents flowing have also been generally disregarded in specifying and demonstrating efficiency owing to the difficulty of obtaining accurate values.

Efficiencies as usually calculated by the summation of loss method are therefore slightly higher than the true values. This fact is now generally understood by those who use electrical machinery, and for the reason that more exact information as to the actual power efficiency is desired by the users, the present agitation for input-output tests began.

To the uninitiated the input-output test appears to be a perfectly simple and the only rational method of measuring efficiency, particularly when both input and output are electrical, as in the case of motor-generators and converters.

From a purely academic standpoint nothing seems easier than to derive efficiency by comparing simultaneous readings of

measuring instruments connected in the incoming and outgoing circuits of electrical apparatus.

Those of us, however, who have conducted some of these tests on circuits other than those of college laboratories can tell a different story. Many factors contribute to invalidate the accuracy of the results obtained. Chief of these is the tendency of ordinary power circuits to fluctuate slightly. Because of this tendency it is extremely difficult to get accurate results when measuring the input to motors. This is especially true in the case of machines having heavy revolving elements rotating at high speeds.

When operating from ordinary power circuits the indicating pointers of ammeters and wattmeters connected in the feeders of such apparatus will often oscillate 25 per cent each way from the mean of a large number of readings.

This tendency of the current to fluctuate has a bearing on the accuracy of all input readings taken while the apparatus is revolving, either with power applied to its own terminals, or when driven by a separate motor.

Referring to the separate loss measurements and to the expression for the losses,

$$\text{Losses} = W_{I^2R} + W_F + W_R + W_E + W_T \quad .$$

it is to be noted that W_F and W_R are measured while the apparatus is revolving and that their measured values, as determined by power input readings, may be in error due to incorrect readings caused by fluctuations of the supply circuit.

From the data given in the foregoing tables we find that the sum of these two losses ranges from 1.4 to 10 per cent of the rated output. Assuming an error of 5 per cent in the driving motor input due to incorrect readings of swinging meter pointers when measuring the no-load losses, the calculated efficiency at rated output will be in error by not to exceed 7/100 of 1 per cent in the one case and ½ of 1 per cent in the other.

Referring now to input-output measurements it is evident that an error of 5 per cent in the input reading will affect the calculated efficiency by approximately the same amount, that is to say the result will be in error by approximately 5 per cent.

The complicated nature of the input-output test, the large number of observers required, and the discrepancies that appear in the results in spite of the exercise of the greatest care, are shown in the following data of an actual test made under the most favorable conditions by a corps of experts.

TABLE A

MOTOR-GENERATOR SET—1200 REV. PER MIN. GENERATOR—150-KW., 250-VOLT, DIRECT-CURRENT, COMPOUND WOUND COMMUTATING POLE. SYNCHRONOUS MOTOR—235-H.P., 4000-VOLT, THREE-PHASE, 60 CYCLES. NATURE OF LOAD-GRID RESISTANCE. CONNECTIONS AS PER DIAGRAM ON FOLLOWING PAGE.

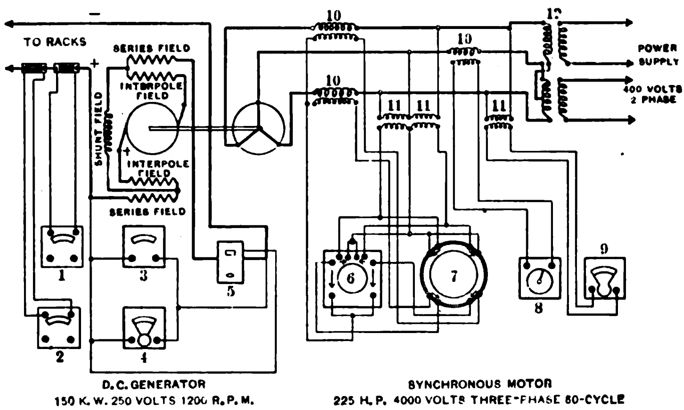
Kw. output			Kw. input		Efficiency by input-output — Using readings of meters corresponding to numbers given						*Efficiency by separate losses
Precision wattmeter No. 5	Ammeter No. 1 Voltmeter No. 3	Ammeter No. 2 Voltmeter No. 4	Indicating wattmeter No. 6	Integrating wattmeter No. 7	1, 3 and 6	1, 3 and 7	2, 4 and 6	2, 4 and 7	5 and 6	5 and 7	
	37.83	37.79	54.90	55.48	68.90	68.20	68.80	68.10			
37.5	37.48	37.42	54.27	54.98	69.10	68.15	68.95	68	69.10	68.20	70.40
	75	74.93	94.17	95.45	79.65	78.55	79.55	78.50			
75	75.10	75	93.99	95.15	79.90	78.93	79.80	78.85	79.80	78.85	79.50
	112	111.60	134.32	135.63	83.85	82.55	83.12	82.28			
112.5	112.60	112.20	134.92	135.73	83.48	82.95	83.17	82.68	83.35	82.82	84 50
	149	149	176.59	176.59	84.40	84.40	84.40	84.40			
150	150	149.90	178.49	179.69	84.04	83.47	84	83.42	84.04	83.47	86
	149.80	149.80	177.25	177.99	84.52	84.20	84.52	84.20			
	187.10	187	220.67	224.16	84.80	83.48	84.73	83.45			
	186.80	186.10	221.33	223.02	84.40	83.76	84.07	83.45			86.50
	187.80	186.70	223.27	222.57	84.10	84.40	83.60	84.09			
	226.30	225.30	266.82	271.85	84.80	83.20	84.40	82.85			
	224.30	223.90	265.69	269.90	84.41	83.10	84.25	82.95			87
	225	224.50	268.80	268.64	83.70	83.78	83.52	83.58			

* No allowance made for "load losses."

For location of meters see corresponding numbers on diagram of connections.

No. 1—Direct-current millivolt-meter with 1000-ampere manganin shunt.
No. 2—Direct-current millivolt-meter with 1000-ampere manganin shunt.
No. 3—Direct-current voltmeter Range 375–750.
No. 4—Direct-current voltmeter. Range 375–750.
No. 5—500-ampere precision wattmeter.
No. 6—60-cycle polyphase indicating wattmeter.
No. 7—60-cycle polyphase integrating watthour meter.
No. 8—Portable alternating-current ammeter.
No. 9—Alternating-current voltmeter.
No. 10—30 to 5 series transformer.
40 to 5 series transformer.
No. 11.—4000 to 100 voltage transformer.
No. 12—400 to 4000-volt, 250-kilowatt power transformers arranged for Scott two-phase three-phase connection.

An observer was stationed at each of the instruments shown in the diagram. In addition several assistants were necessary



INPUT-OUTPUT TESTS, MOTOR-GENERATOR SET
DIAGRAM OF CONNECTIONS

in order to properly control the supply circuit and to maintain constant load.

The test was conducted as follows:

Having adjusted the voltage and current of the generator, and the power factor, voltage and frequency of the motor supply circuit, at each load a series of simultaneous readings was taken at definite time intervals. The signal to read was given by blowing a whistle. Ten readings, five seconds apart, were taken at each load and the average of these ten readings was considered the true value.

Notwithstanding the precautions taken to insure accuracy an examination of the tabulated results shows that the efficiencies

indicated by the readings of different instruments differ by as much as 2 per cent.

It is to be noted that the use of current and potential transformers or other multipliers necessary in tests of this kind increases the liability of error.

In addition to the fluctuations of the supply circuit another contributing factor tending to inaccuracy is the variation in the generator load due to changes in the resistance of that circuit. If grid resistance or water rheostats are employed for loading, fluctuations will occur due to slight changes in the temperature of the water or metal used. These fluctuations will affect all of the measuring instruments. If the current is "pumped back" into a power circuit the tendency of such circuits to oscillate will be magnified, causing greater swinging of the meter pointers.

The use of integrating instruments has been proposed as a solution of the difficult problem of accurately measuring the fluctuating currents during these tests. It is argued that if such instruments were used and comparative readings taken in both incoming and outgoing circuits over a long period of time, the true value of efficiency would be indicated.

Tests which have been conducted according to this plan have not been satisfactory. In fact the results have been uniformly much more unreliable than with indicating instruments. This is due to the inherent inaccuracy of the integrating meters and particularly of the heavy capacity direct-current watt-hour meter. No heavy capacity instrument of this type with which the writer is acquainted can be relied on to give correct values within 2 per cent.

In discussing the derivation of efficiency by the summation of loss method it has been pointed out that at any given load the only losses which cannot be accurately determined from no-load measurements are the rotation loss and the loss due to eddy currents caused by the stray fields of useful currents.

Therefore the empirical correcting factors which it is proposed to use in connection with the no-load values of the separate losses would be applied to these losses only, and not to the sum of all the losses.

The data given in Tables B and C, at the end of this paper, show the use of these constants in working up some actual tests. A comparison is made between the efficiencies obtained from input-output tests with those computed by the separate loss method using correcting factors as outlined above.

The data cover tests of direct-current motors, induction motors, motor-generators and synchronous converters. The tests of motors are all average tests, that is, they have been taken at random from a large number of tests made by average men, who did not have in mind the determination of load-loss constants when making the tests.

The constants used are the averages of those indicated by a number of very careful input-output tests of motor-generators. Two of these were made for the particular purpose of determining these constants. The same constants are used in all cases for the same types of machines and it is worthy of note that the results throughout are fairly uniform. In some cases the values run higher by separate losses and in some cases lower, than by input-output.

Two different constants have been used, constant K, a multiplying factor applied to the I^2r loss values to compensate for eddy current losses under load, and constant K', applied to the rotation loss values to compensate for increased losses due to field distortion.

The values of K and K' will vary over a considerable range depending upon the characteristics of the apparatus.

In the case of both alternating- and direct-current machines of low frequency, K is in most cases but slightly greater than unity, but for the higher frequencies this constant is considerably greater, especially with machines having deep slots and conductors of large cross section.

The value of K' for compensated machines, such as induction motors and synchronous converters, is but little, if any, greater than unity, whereas in non-compensated generators and motors with large field distortion, K' may be as high as two at rated load.

Attention is called to the data in Table D relating to input-output tests of 15 induction motors made under average conditions. In working up the efficiencies from the separate losses no multiplying factors were used, as load losses were considered negligible. When compared with the efficiencies obtained by prony brake, in nine cases the efficiency is lower by the separate losses than by input-output, showing not only the unreliability of the prony brake, but also that the load losses, if any, are so small that they can be ignored.

In Table E, data are given relating to some careful input-output tests of a 50-kw. motor-generator and of a 1000-kw. synchronous converter.

Considering first the motor-generator data, Table E, tests No. 1, 2, 3 and 4 refer to separate and distinct tests made on different days, by the same observers with the same instruments. Although the conditions were as near ideal as possible and extreme care was taken, the results, which should have been identical, showed a maximum variation of 2.3 per cent.

In the case of the synchronous converter, four tests were made with different sets of instruments, each of which had been adjusted and carefully calibrated immediately before the tests were made. As much care was exercised as in the case of the motor-generator but the results show discrepancies of as much as 2.4 per cent in efficiency.

In these synchronous converter tests, as in several others made under the writer's supervision, the efficiencies by input-output very frequently show higher than by the separate losses, indicating that load losses in machines of this type are a negligible quantity.

It is not contended that the constants used in working up these tests are the values that will finally be indicated after a large amount of data has been collected. The data submitted herein are given to demonstrate the method and not to indicate the values of the constants. It is conceded that an insufficient number of accurate test records are available at present to establish the values of these constants. It is doubtful if such records are in existence, as the writer's investigations lead him to believe that surprisingly few accurate input-output tests have been made. This belief is based not only on his own experience but also on conversations and correspondence with engineers in different localities.

It is urged that those who have data bearing on this subject will bring them forward and that hereafter the determination of these constants will be kept in mind when efficiency tests are being made.

The fact that these figures are not available does not indicate that few input-output tests have been conducted. On the contrary they have been made repeatedly. Few engineers however have had the time, the money, or the patience necessary to obtain accurate results. The average input-output test of motor-generators and converters is perhaps accurate within $1\frac{1}{2}$ to 2 per cent. Motor efficiency by prony brake probably averages between 1 and $1\frac{1}{2}$ per cent of the true value.

In conclusion it may be stated that efficiency guarantees

based upon the summation of the separate losses without change to allow for increases due to load, are entirely satisfactory as a basis for comparing one manufacturer's machines with those of any other maker. It is true that the actual efficiencies in either case will in some types of machines be slightly lower than those indicated by the separate losses. But, for the same separate no-load losses, the load losses will be practically identical, provided the temperatures, the regulation and the commutation correspond.

It is of course desirable that the actual efficiencies be known and it is the writer's opinion that the simplest and most accurate method for determining the true values is by the summation of losses with some correcting factors as described in this paper. Ultimately he believes that this general method should be adopted as the Institute standard.

TABLE D
INDUCTION MOTORS

Kw. Input	Kw. output		Efficiencies		Discrepancy
	Input minus losses	Input-output test	*By separate losses	†By input output test	
40.3	36.7	37.3	91.1	92.5	+1.4
42.2	38	37.3	90	88.5	-1.5
41.3	37	37.3	89.5	90.3	+0.8
40.9	36.9	37.3	90.2	91.2	+1
50	44.4	44.76	88.8	89.6	+0.8
62.2	57.2	56	92	90	-2
60.1	55.3	56	91.9	93.2	+1.3
62.5	56.5	56	90.3	89.6	-0.7
61.4	56.1	56	91.3	88	-3.3
4.4	3.8	3.73	86.3	85	-1.3
6.63	5.53	5.6	83.4	84.5	+1.5
12.45	11.13	11.2	89.3	90	+0.7
16.34	14.78	14.92	90.2	91.1	+0.9
119.5	119.5	111.9	93.5	93.5	0
29.4	25.55	26.1	86.8	88.8	+2

*No allowance made for "load losses."
†Mechanical output by prony brake.

TABLE B
MOTOR-GENERATORS

	Frac. load	Synchronous motor W_{I^2R} (stator)	Synchronous motor K	Synchronous motor $K\ W_{I^2R}$	Direct-current generator W_R	Direct-current generator K'	Direct-current generator $K'\ W_R$	Total load losses	Total output in kw.	Total Input: Output plus losses	Total Input: Input output test	Total Input: By use of constants	Efficiencies: *1 By separate losses	Efficiencies: 2 By Input output test	Efficiencies: 3 By use of constants	Difference between 2 & 3
1000-kw. 250-volt	1/2	2.54	1	2.54	16.5	1.4	23.1	6.6	502.4	606.5	607.2	613.1	82.8	82.75	81.9	-0.85
514 rev. per min. inter-pole generator	3/4	5.72	1.05	6.	16.8	1.7	28.6	12.08	751.8	867.5	873.5	879.6	86.7	86.08	85.5	-0.58
1440-h.p. 13,200-volt	4/4	10.14	1.1	11.15	17.1	2	34.2	18.11	989.9	1117	1135	1135	88.5	87.23	87.23	0
synchronous motor	1¼	15.9	1.2	19.1	17.4	2.4	41.7	27.5	1254	1403	1435	1433	89.5	87.43	87.4	-0.03
150-kw. 250-volts	1/2	.63	1	.63	1.95	1.4	2.73	0.78	75	94.9	95.2	95.2	79.5	78.8	78.8	0
1200 rev. per min. inter pole	3/4	1.42	1.05	1.49	2.1	1.7	3.57	1.74	112.5	133.3	134.9	135.04	84.5	83.5	83.1	-0.4
generator 225-h.p.	4/4	2.52	1.1	2.77	2.3	2	4.6	2.55	150	174.4	178.5	176.95	86	84	84.7	+0.7
4000-volt synchron-	1¼	3.94	1.2	4.73	2.5	2.4	6	4.29	186.9	216	221.8	220.3	86.5	84.3	84.7	+0.4
ous motor	1¼	5.68	1.5	8.5	2.7	2.8	7.55	7.67	224.9	258.7	267.1	266.4	87	84.2	84.4	+0.2

*No allowance made for "load losses."

TABLE C

DIRECT-CURRENT MOTORS

Machine	Fractional oads	Assumed constant K'	W_R at no-load	W_R under load	Kw. input	Kw. output: No. 1 Input minus losses	Kw. output: No. 2 Output test	Kw. output: No. 3 By use of K'	Efficiencies: *No. 1 By separate losses	Efficiencies: †No. 2 By input-output	Efficiencies: No. 3 By use of K'	Difference between 2 and 3
20-h.p., 230-volt	2/4	1.4	0.244	0.341	8.76	7.61	7.46	7.51	86.9	85.2	85.8	+0.6
650 rev. per min.	3/4	1.7	0.240	0.408	12.77	11.32	11.19	11.17	88.7	87.6	87.5	—0.1
d-c. commutating	4/4	2.0	0.230	0.460	17.00	15.15	14.92	14.97	89.2	87.9	88.1	+0.2
pole motor	5/4	2.4	0.218	0.523	21.50	19.05	18.65	18.75	88.7	86.9	87.3	+0.4
	6/4	2.8	0.208	0.583	26.63	23.35	22.38	22.85	87.6	84.3	85.7	+1.4
20-h.p., 115-volt	2/4	1.4	0.270	0.378	8.87	7.52	7.46	7.43	84.7	84.1	83.7	—0.4
650 rev. per min.	3/4	1.7	0.263	0.447	13.04	11.40	11.19	11.24	87.3	85.8	86.1	+0.3
d-c. commutating	4/4	2.0	0.248	0.496	17.30	15.18	14.92	14.99	87.7	86.3	86.6	+0.3
pole motor	5/4	2.4	0.230	0.553	21.73	18.90	18.65	18.63	87.0	85.9	85.7	—0.15
	6/4	2.8	0.215	0.581	26.38	22.70	22.38	22.25	86.0	84.9	84.4	—0.5
25-h.p., 115-volt	2/4	1.4	0.450	0.630	11.23	9.58	9.32	9.42	85.3	83.0	83.8	+0.8
825 rev. per min.	3/4	1.7	0.440	0.748	16.38	14.38	13.98	14.11	87.8	85.4	86.2	+0.8
d-c. commutating	4/4	2.0	0.420	0.840	21.75	19.20	18.65	18.84	88.4	85.7	86.7	+1.0
pole motor	5/4	2.4	0.400	0.960	27.36	24.13	23.30	23.72	88.3	85.1	86.7	+1.6
	6/4	2.8	0.385	1.178	33.30	29.10	27.95	28.41	87.5	84.0	85.5	+1.5
30-h.p., 230-volt	2/4	1.4	0.433	0.607	12.97	11.33	11.20	11.19	87.4	86.3	86.2	—0.05
975 rev. per min.	3/4	1.7	0.428	0.728	19.06	17.11	16.80	16.88	89.8	88.2	88.5	+0.3
d-c. commutating	4/4	2.0	0.418	0.836	25.08	22.77	22.38	22.38	90.7	89.2	89.2	0
pole motor	5/4	2.4	0.405	0.973	31.12	28.30	27.95	27.80	90.9	89.9	89.2	—0.7
	6/4	2.8	0.393	1.100	37.28	33.81	33.55	33.20	90.7	90.0	89.0	—0.1
35-h.p., 230-volt	2/4	1.4	0.783	1.100	15.60	13.58	13.06	13.30	87.0	83.7	85.2	+1.5
1150 rev. per min.	3/4	1.7	0.770	1.310	22.70	20.30	19.58	19.80	89.4	86.3	87.2	+0.9
d-c. commutating	4/4	2.0	0.755	1.510	29.70	26.93	26.10	26.20	90.6	87.9	88.3	+0.4
pole motor	5/4	2.4	0.740	1.770	86.80	33.45	32.65	32.55	91.0	88.8	88.5	—0.3

*No allowance made for "load losses."

†Mechanical output by prony brake.

TABLE C DIRECT-CURRENT MOTORS (*Continued*)

Machine	Fractional loads	Assumed constant K'	W_R at no-load	W_R under load	Kw. input	Kw. output			Efficiencies			Difference between 2 and 3
						No. 1 Input minus losses	†No. 2 Output test	No. 3 By use of K'	*No. 1 By separate losses	†No. 2 By input-output	No. 3 By use of K'	
40-h.p., 230-volt	2/4	1.4	1.300	1.820	18.56	15.38	14.92	14.93	82.8	80.4	80.5	—0.1
1100 rev. per min.	3/4	1.7	1.280	2.175	26.50	23	22.38	22.25	86.7	84.3	83.8	—0.5
direct-current	4/4	2.0	1.260	2.520	34.50	33.50	29.84	29.60	89.0	86.5	85.7	—0.75
motor	5/4	2.4	1.240	2.980	42.50	38.30	37.30	36.83	90.1	87.8	86.7	—1.1
	6/4	2.8	1.210	3.390	50.50	45.85	44.76	43.85	90.9	88.6	86.8	—1.8
40 hp., 230 volt	2/4	1.4	0.750	1.050	17.98	15.10	14.92	14.90	84.0	83.0	82.8	—0.2
850 rev. per min.	3/4	1.7	0.740	1.257	26.05	22.88	22.38	22.40	87.8	86.0	86.1	+0.1
direct-current	4/4	2.0	0.730	1.460	34.40	30.73	29.84	30.15	89.3	86.9	87.6	+0.7
motor	5/4	2.4	0.720	1.725	42.70	38.48	37.30	37.60	90.1	87.4	88.0	+0.6
	6/4	2.8	0.710	1.990	51.20	46.40	44.76	45.15	90.7	87.5	88.2	+0.7
50-h.p., 230-volt	2/4	1.4	1.060	1.485	22.12	19.10	18.65	18.73	86.4	84.2	84.7	+0.55
750 rev. per min.	3/4	1.7	1.040	1.770	31.80	28.65	28	27.93	90.0	88.1	87.8	—0.3
direct-current	4/4	2.0	1.020	2.040	41.50	37.95	37.30	37	91.4	89.9	89.2	—0.1
motor	5/4	2.4	1.000	2.400	51.45	47.25	46.70	45.90	91.9	90.9	89.3	—1.6
	6/4	2.8	0.985	2.760	62	57.30	56	55.80	92.5	90.3	90.0	—0.3
60-h.p., 230-volt	2/4	1.4	1.500	2.100	25.96	22.39	22.38	21.85	86.4	86.3	84.4	—1.9
650 rev. per min.	3/4	1.7	1.480	2.520	28.10	34.20	33.60	33.25	89.8	88.2	87.3	—0.9
direct-current	4/4	2.0	1.460	2.920	50.20	45.88	44.76	44.60	91.4	89.2	88.8	—0.4
motor	5/4	2.4	1.440	3.460	62	57.25	56	55.40	92.3	90.2	89.4	—0.8
	6/4	2.8	1.415	3.970	73.90	68.50	67.10	66.15	92.7	90.8	89.5	—1.3

*No allowance made for "load losses."

† Mechanical output by prony brake.

TABLE E

MOTOR-GENERATOR INPUT-OUTPUT TEST

75-H.P., THREE-PHASE, 60~, 2300-VOLT INDUCTION MOTOR; 50-KW., 95-VOLT, COMPOUND WOUND, DIRECT-CURRENT GENERATOR

Test No. 1		Test No. 2		Test No. 3		Test No. 4		Efficiencies*				
Input	Output	Input	Output	Input	Output	Input	Output	Test No. 1	Test No. 2	Test No. 3	Test No. 4	Losses
33.5	25.64	33.04	25.1	32.66	24.9	34.07	26.45	76.67	76	76.2	77.8	77.9
32.8	24.88	32.2	24.6	32.6	24.9	33.05	25.5	75.97	76.45	76.3	77	
47.6	37.39	48.13	38.35	48.43	38	48.7	38.2	78.5	79.7	78.4	78.5	80.2
47.9	37.54	48.32	38.01	48.7	38.2	48.3	38.4	78.3	78.6	78.3	79.5	
63.2	50	63.1	50.5	64.8	51	61.9	50	79.1	80	78.75	80.8	81
63.9	50.48	63.1	51	64.53	50.6	62.7	50.7	79.03	80.7	78.4	80.6	

SYNCHRONOUS-CONVERTER INPUT-OUTPUT TEST

1000-KW.,—615 VOLTS, DIRECT CURRENT—SIX-PHASE—25~, EIGHT-POLE

Test No. 1		Test No. 2		Test No. 3		Test No. 4		Efficiencies*				
Input	Output	Input	Output	Input	Output	Input	Output	Test No. 1	Test No. 2	Test No. 3	Test No. 4	Losses
525	507.5	528.7	494.8	529	507.5	524.6	494.8	96.73	93.6	95.98	94.3	95
757.7	740.4	755	736.6	762.5	740.4	755	736.6	97.83	97.54	97.25	97.53	96.3
1038	1003	1053	993.8	1053	1003	1032	993.8	96.53	94.2	95.28	96.23	96.9

*No allowance made for "load losses."

A paper presented at the 29th Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June 28, 1912.

TO MEASURE AN ALTERNATING-CURRENT RESISTANCE AND COMPARE IT WITH THE DIRECT-CURRENT RESISTANCE—ELECTRO-DYNAMOMETER METHOD.

BY EDWIN F. NORTHRUP.

For comparing an alternating-current and a direct-current resistance by the electrodynamometer method in a precise manner the apparatus required is a frequency meter to measure the frequency of the current used (which must be known, as the quantity being measured will vary with frequency), an alternating-current ammeter to give roughly the value of the current (for the alternating-current resistance will also, in general, depend upon the value of the current), a three-point double-throw switch for quickly changing connections, resistances, and an electrodynamometer. This last piece of apparatus should have sufficient capacity in its current coils to carry, without heating, the full current. Its hanging or potential coils should be two in number, and so arranged as to form a system which is perfectly astatic in respect to the earth's field. The constant of the instrument will then be the same for direct and alternating currents. All good electrodynamometers are constructed in this way. Either the Rowland deflection type or Siemens type, constructed to be astatic, may be used. The method to be described was tested with a Rowland deflection type electrodynamometer.

Description of Circuits and Theory of Method

In I and II, Fig. 1, *G*, *G*, are the fixed coils and *h*, *h*, the hanging astatic system of the electrodynamometer. The hanging

system has an ohmic resistance, α, and there is joined in series with this a non-inductive resistance, ρ'. Let $\rho' + \alpha = \rho$, the entire resistance of the hanging coil system. In the instrument referred to the resistance α is about 18 ohms. It has a minute inductance, which is approximately 0.00045 henry. When ρ' is moderately large and non-inductive, we may consider, without sensible error, that the alternating-current through the hanging system is in phase with its e.m.f. even when the frequency is high. We shall so consider it in all that follows.

A represents a coil which contains iron. It is assumed that this coil has a certain ohmic resistance, R_{dc}, as measured by direct current, and a different resistance, R, as measured by an alternating current of a given value, wave form, and frequency. It is this latter resistance (not the impedance or inductance of A) which the method will enable us to determine. The resistance, r, is any resistance capable of carrying the full current. It may be a coil inductively wound but it must *not* contain iron or have such a

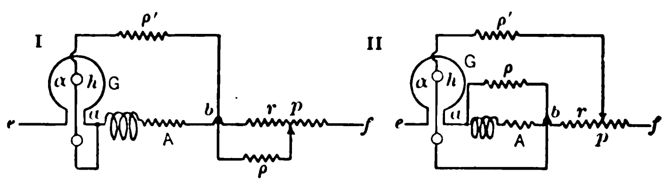


FIG. 1.

section and resistivity that its resistance on alternating current will be different from its resistance on direct current, due to hysteresis, skin effect, or other cause. By a sliding contact, p, means must be provided for tapping upon this resistance at any point along its length as the diagram illustrates. ρ is a non-inductive resistance, which is equal to $\alpha + \rho'$, the resistance of the hanging coil circuit. As will be shown later, the connections can instantly be changed from the arrangement shown in I to that shown in II and vice versa.

We wish first to find the general expression for the power which the wattmeter measures when the connections are those shown in I, Fig. 1. Call I the current in the fixed coils of the dynamometer. Call i the current in the hanging coil circuit. Call φ the phase angle between the currents i and I. Then the deflection of the dynamometer is

$$D = K\, I\, i \cos \varphi \qquad (1)$$

where K is the instrumental constant of the dynamometer. This constant in the case of a deflection instrument of the Rowland type will change slightly with the magnitude of the deflection. There is also an inductive action of the current in the fixed coil which tends to induce a current in the hanging coil circuit when the plane of the movable system is not vertical to the plane of the fixed coils. This inductive action may vary in a complicated way, so equation (**1**) cannot be taken as strictly true. If, however, the system is deflected by means of the torsion head when there is no current through the instrument, so that when current is introduced the system is brought back to the position where its plane is vertical to the plane of the fixed coils, then the inductive action is null and the relation given by equation (**1**) may be considered to hold very exactly. In the use of the dynamometer which follows, the system should be deflected by means of the torsion head when there is no current flowing, to such an extent that, on introducing current, the instrument reads roughly at the zero of the scale. With this precaution observed the theoretical relations will be found to hold very exactly.

If we call V the impressed e.m.f. between the points a and b, I, Fig. 1, then the current through the hanging coil circuit will be

$$i = \frac{V}{\alpha + \rho'} = \frac{V}{\rho} \tag{2}$$

As above stated, the current i will be approximately in phase with the e.m.f., V, because the inductance of the hanging coils is very minute.

By equations (**1**) and (**2**) we have

$$D = \frac{K}{\rho} I\, V \cos \varphi \tag{3}$$

But $I\, V \cos \varphi$ is the entire power, W_t. This power is the sum of two parts, W, the power consumed in A. (I, Fig. 1) between the points a and b, and W', the power consumed in the hanging coil circuit. The value of this latter is

$$W' = \frac{V^2}{\rho} \tag{4}$$

Thus we have

$$D = \frac{K}{\rho} W_t \tag{5}$$

or

$$D = \frac{K}{\rho}\left(W + \frac{V^2}{\rho}\right) \tag{6}$$

From equation (6)

$$W = \frac{\rho}{K} D - \frac{V^2}{\rho} \tag{7}$$

and from equation (5)

$$W_t = \frac{\rho}{K} D \tag{8}$$

$\frac{V^2}{\rho}$ is generally a small quantity. ρ is known very precisely and V can be obtained with a voltmeter, hence equation (7) enables the true power spent in A to be accurately obtained. It is equation (8), however, which we wish to use in measuring the alternating-current resistance of A.

With the connections as shown in I, Fig. 1, the torsion head is turned, so that, with the current (as steady as possible) which is flowing, the deflection reads near the zero of the scale. The total power then being registered is given by equation (8).

The connections are now quickly changed to those shown in II. The main current will not be altered by this change in connections, for the resistance ρ is simply made to change places with an equal resistance. The total power which is registered, however, will now be

$$W_t' = \frac{\rho D'}{K} \tag{9}$$

when D' is the deflection which the dynamometer now gives. The contact, p, is moved along the resistance, r, until the deflection D' is made equal to the deflection D, then W_t' will be equal to W_t.

Since the main current, I, is the same for the connections I and II, we have

$$W_t = I^2 R' = I^2 r' \tag{10}$$

or

$$R' = r' \tag{11}$$

Here the quantity R' is not the alternating-current resistance of the coil A but it is the alternating-current resistance of this coil when shunted with the non-inductive resistance ρ. Similarly r' is the alternating-current resistance of r when shunted with the non-inductive resistance ρ.

We can write

$$R' = \frac{\rho R}{\rho + R} K \qquad \text{and } r' = \frac{\rho r}{\rho + r} k$$

The alternating-current resistance of two parallel circuits when one or both of the branches contain reactance is not given by the same expression as applies when the branch circuits are without reactance; hence the ordinary expression for branch circuits without reactance, namely $\frac{\rho R}{\rho + R}$, must be multiplied by some factor K the value of which we now have to determine: also the factor k. It is shown in "Alternating Currents" by Bedell and Crehore, pages 238 to 241, how the alternating-current resistance, or, as they call it, the equivalent resistance of any number of parallel circuits having self-induction and carrying alternating current, may be expressed. It is there shown that in general

$$R' = \frac{A}{A^2 + B^2 \omega^2} \text{ where}$$

$$A = \frac{R_1}{R_1^2 + x_1^2} + \frac{R_2}{R_2^2 + x_2^2} + \quad . \quad . \quad . \quad = \sum \frac{R}{R^2 + x^2}$$

and

$$B\omega = \frac{x_1}{R_1^2 + x_1^2} + \frac{x_2}{R_2^2 + x_2^2} + \quad . \quad . \quad . \quad = \sum \frac{x}{R^2 + x^2}$$

in which expressions R_1, R_2, etc., are ohmic resistances and x_1, x_2, etc., are reactances of the several branches.

We can now find expressions which will give the values of K and k.

Here we have

$$A = \frac{1}{\rho} + \frac{R}{R^2 + x^2}$$

and

$$B\omega = \frac{x}{R^2 + x^2}$$

We cannot, because of the necessity of brevity, give here the purely algebraic processes required for obtaining the final expressions and so we shall present only the final results, which are as follows

$$K = 1 + \frac{\rho\, x^2}{[(R+\rho)^2 + x^2]\, R}$$

$$k = 1 + \frac{\rho\, x_1^2}{[(r+\rho)^2 + x_1^2]\, r}$$

Call the fractional expressions α and α_1 respectively, then $K = 1 + \alpha$ and $k = 1 + \alpha_1$.
This gives

$$\frac{R}{\rho + R}(1 + \alpha) = \frac{r}{\rho + r}(1 + \alpha_1).$$

It will be shown that, in general, when a sensitive electrodynamometer is used, α and α_1 are very small quantities which in most cases can be neglected.

We have the following cases:

1. α and α_1 are negligible. Then

$$R = r \tag{12}$$

2. α and α_1 are not negligible but are very nearly equal. Then again $R = r$

In these two cases the alternating-current resistance sought may be taken as numerically equal to the resistance r.

3. $\alpha_1 = o$ but α is not negligible. In this case

$$R = r \frac{1}{1 + \alpha \frac{\rho + r}{\rho}} \tag{13}$$

4. α and α_1 are not negligible and are unequal but ρ is very large. Then again we can take $R = r$.

Consideration of a single example of the third case will suffice to show the magnitude of the error which may be introduced by omitting the correction. The example chosen is from an actual measurement. With the electrodynamometer available, only 1/10 ampere could be passed through the fixed coil and hence, the potential drop over the coil A and over the resistance r being small, the resistance ρ had necessarily to be taken very small to

give the requisite sensibility. If the dynamometer coils could have carried (as is ordinarily the case) several amperes, ρ would have been much larger and the error would be much less. In the example $\alpha_1 = o$ and

$$\alpha = \frac{\rho\,(2\,\pi\,N\,L)^2}{[(R+\rho)^2 + (2\,\pi\,N L)^2]\,R}$$

$$= \frac{300\,(2\times 3.14\times 60\times 0.036)^2}{[(11\times 300)^2 + (2\times 3.14\times 60\times 0.036)^2]\ 11}$$

or $\alpha = 0.052$ nearly.

Hence,

$$R = r\,\frac{1}{1 + 0.052\,\frac{311}{300}} = 0.948\,r.$$

Thus if we had called $R = r$ the error would have been about 5.2 per cent, R being assumed too large. This conclusion was checked experimentally. Without changing the ohmic resistance of the coil A, its inductance, which was capable of variation, was varied from 0.003 to 0.036 henry, and in the first case, using the uncorrected formula $R = 10.94$ ohms, and in the second case, using the same formula, $R = 11.62$ ohms, or six per cent too large, which is in fairly close agreement with the calculated result of 5.2 per cent.

If the fixed coils of the dynamometer had been made to carry 10 amperes instead of 1/10 ampere ρ could have been 100 times as large, in which case the correction factor would reduce to about 0.05 per cent.

The above adjustments having been made, direct current can be made to replace the alternating current and in the same way we find the direct-current resistance of A. It will be

$$R_{dc} = r_1 \tag{14}$$

Hence

$$\frac{R}{R_{dc}} = \frac{r}{r_1}\,. \tag{15}$$

is the ratio of the alternating-current to the direct-current resistance of the circuit A. This ratio may take a value of two or more.

It should be clearly understood just what is meant by the quantity R which this method measures. It is a quantity which, expressed in ohms and multiplied by the square root of the mean square value of the alternating current through the circuit, expressed in amperes, will give the square root of the mean square value of that component of the impressed e.m.f. expressed in volts which is in phase with the current. Or, it is the quantity which, when multiplied by the mean square value of the current, will give the power in watts which is being dissipated in the circuit. In drawing the triangle of e.m.fs. of an inductive circuit one sometimes represents the component of the e.m.f. which is phase with the current by the product of the current and the direct current resistance, R_{dc}. This procedure may lead to considerable error in circuits in which there

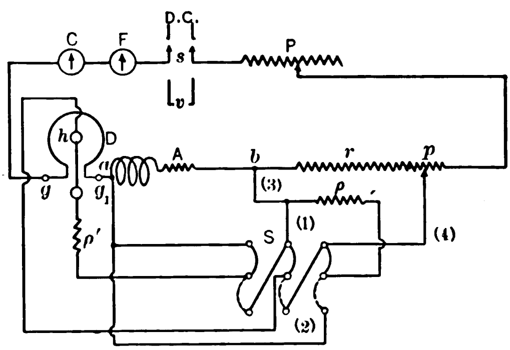


FIG. 2.

are other losses than the $I^2 R_{dc}$ losses. In such circuits the alternating-current resistance, R, should always be used.

METHOD OF EXECUTION

For making the above measurement the apparatus is assembled and connected as shown in Fig. 2.

D is the electrodynamometer with its hanging system h. The heavy or light wire fixed coils are used according to the magnitude of current with which the measurement is to be made. The light wire fixed coils will carry (in the Rowland instrument) 0.1 ampere and the heavy wire coils will carry 50 amperes.

C is the alternating-current ammeter and F the frequency meter. P is a rheostat to control the main current; s is a switch to shift from direct-current to alternating-current and vice

versa. S is the three-point double throw switch which in position (1) makes the connections shown in I and in position (2) makes the connections shown in II, Fig. 1. r is best obtained from a slide wire rheostat of considerable current capacity. It does not need to be non-inductive, but must contain no iron. If its reactance is just equal to that of the coil being measured, $\alpha = \alpha_1$ and $R = r$ exactly.

After the settings for p have been found, the connections are broken at (3) and (4) and the direct-current resistance value of r is measured with a Wheatstone bridge or by any other convenient means.

The resistances ρ and ρ' may be obtained best from plug or dial decade resistance boxes. These may be high, 10,000 ohms or so, depending entirely upon the current used, the magnitude of the resistance being measured, and upon the sensibility of the instrument.

The torsion head may be turned so that the no-current deflection is between 100 and 200 divisions of the scale. By then adjusting p the deflection with current on may be made to come near the zero of the scale.

It will be found, if A consists of an ironless variable standard of inductance, that the variable standard may be set to any inductance value without much altering the deflection. The change in the deflection will be less as ρ is made larger.

This method will be found useful in measuring the alternating-current resistance of steel-cored copper or aluminum cables, which differs considerably from their direct-current resistance.

The following test of this method was made for the purpose of showing how large a correction would be required when ρ was chosen only 300 ohms and L was varied between 0.003 and 0.036 henry.

The resistance measured was that of a variable standard of inductance, which should, of course, show the same value on direct and alternating current, at whatever value its inductance is set.

(a) L = 0.003 henry.

With alternating-current in circuit.

D_t = 244 (no current).

D = D' = 0 (current flowing).

R = r = 10.94 ohms.

I = 0.08 ampere.

N = 60.2 cycles.

ρ = 300 ohms.

(*b*) L = 0.036 henry.

With alternating-current in circuit.

D_t = 253 (no current).

D = D' = 0 (current flowing).

R = r = 11.62 ohms.

I = 0.08 ampere.

N = 60.2 cycles.

ρ = 300 ohms.

With direct-current in circuit.

D_t = 244 (no current).

D = D' = 0 (current flowing).

R_{dc} = r = 10.94 ohms.

I_{dc} = 0.08 ampere.

ρ = 300 ohms.

A paper presented at the 29th Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June 26, 1912.

INDUSTRIAL ILLUMINATION AND THE AVERAGE PERFORMANCE OF LIGHTING SYSTEMS

BY C. E. CLEWELL

Illumination in the past has been looked upon largely as an accessory. Modern illuminating engineering, however, is concerned with the adaptation of the available types of lamps to certain supply circuits, to various classes of service, and to given conditions of building construction.

A few years ago the older type of arc lamp and the carbon filament lamp, typifying a large and a small unit, covered the range of types of lamps available for illumination work in the industries. This limitation in candle-power has gone through an evolution by the introduction in more recent years of the enclosed arc, the open flame-carbon arc, the metallic flame arc and the long burning flame carbon arc lamp, as improvements on the original arc lamp; and the metallized filament, the tantalum and the tungsten lamp, as improvements on the original filament lamp. The Moore tube, the Nernst and the mercury vapor lamps are also available as new types.

The candle-power values of these various lamps are shown in Fig. 1 where, in an approximate manner, the average mean spherical candle-power values of all types, both old and new, are indicated. Fig. 2 shows the over-all dimensions of the various lamps, from which it is apparent that the dimensions for given candle-power values have been modified by changes in design.

Re-directing the light where most useful should be included in development of high efficiency lamps as additional to the matter of total light flux per watt. The growing tendency to rate electric lamps according to the effective illumination produced on the work rather than in terms of the watts per mean spherical

candle-power is evidence that this item will probably be included in the considerations of lamp efficiency more in the future than in the past.

Quantity of light is no longer the sole criterion of excellence, but its uniformity over the work, diffusion, adequate intensities on the sides of the work, absence of glare, color values and similar items are now given an importance almost if not quite equal to mere satisfaction in the matter of vertically downward intensities.

Factory work generally speaking may be grouped into work on a horizontal plane, as bench work of some kinds, which, in

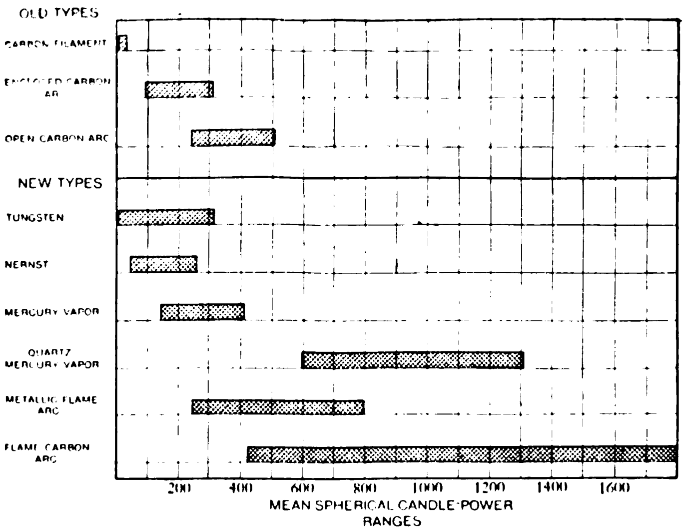


Fig. 1.—Average Candle-Power Ranges of Old and New Lamps.

the main, requires only downward illumination; and other work such as that included under machine tool operations, foundry moulds, rolling mills, assembly, and the like, where, in addition to vertically downward light, side components effective on vertical planes, as well as shadow elimination, play an important part in the excellence of results.

The height of ceiling, roof or trusses limits in a very large measure the size and type of lamp to be employed. Experiment and usage demonstrate the disadvantage of using very large lamps for low ceilings, while lack of economy prohibits the use of small lamps for high areas. In former years arc lamps were used for

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FIG. 3.—FACTORY SPACE FREE FROM OBSTRUCTIONS.

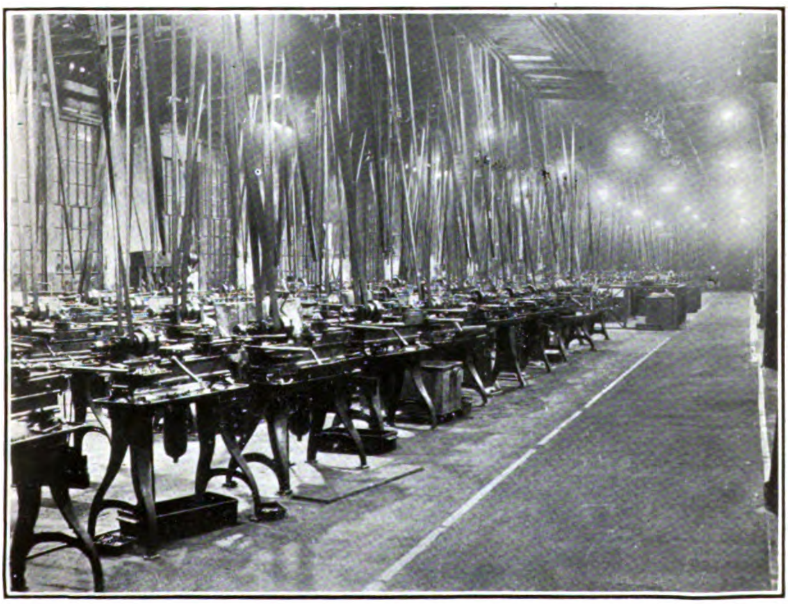

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FIG. 4.—FACTORY SPACE WHERE MUCH BELTING IS USED.

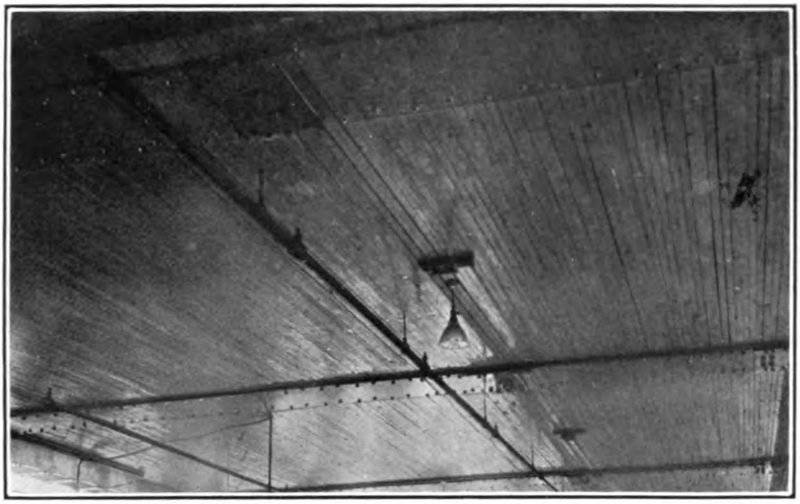

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FIG. 5.—WOOD CEILING FLUSH WITH UNDER SIDE OF GIRDERS.

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FIG. 6.—WOOD CEILING DIVIDED BY DEEP IRON GIRDERS.

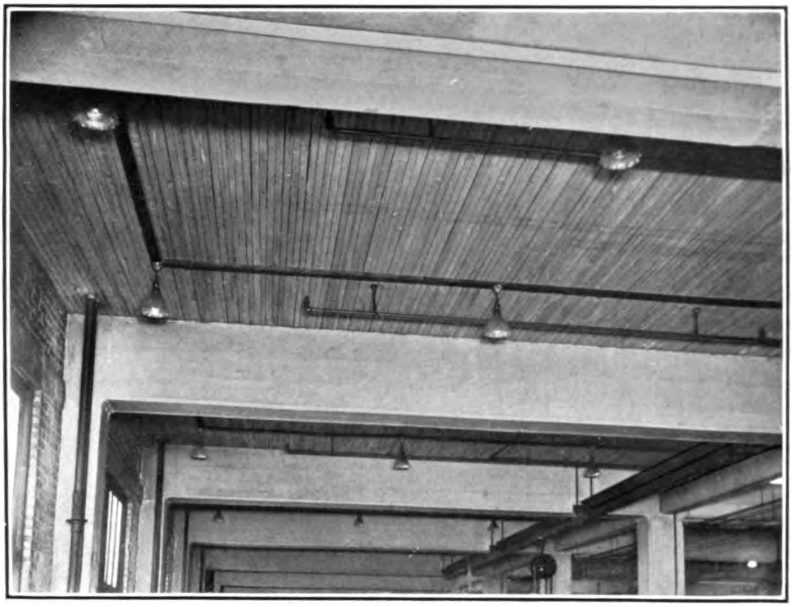

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FIG. 7.—WOOD CEILING DIVIDED BY CEMENT-COVERED GIRDERS.

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FIG. 8.—OPEN GIRDER CONSTRUCTION—NO CEILING.

low factory bays, while in some extremes no appreciable general illumination was possible due to the absence of sufficient clearance between cranes and ceiling for an arc lamp. In like manner very high bays have been inadequately lighted due to the lack of lamps possessing sufficient candle-power and suitable distribution characteristics. To-day, however, lamps of enormously greater candle-power and more suitable distribution are available for the higher areas, while lamps with corresponding advantages are available for low areas.

Open spaces simplify the problem by permitting the use of lamps spaced comparatively far apart, while the interference of belting calls for a type and arrangement of lamps which will provide diffusion, so as to reduce the shadows ordinarily pro-

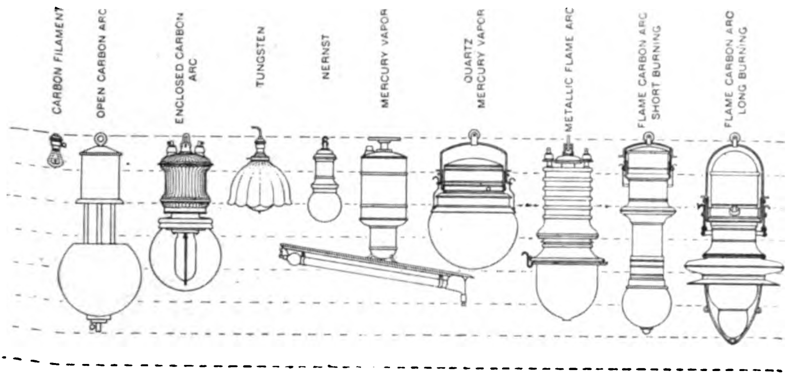


FIG. 2.—CHART SHOWING RELATIVE AVERAGE OVERALL DIMENSIONS OF VARIOUS LAMPS.

duced by belts. In an atmosphere filled with dust and dirt a penetrating light should be employed, and in spaces of the latter class the maintenance is apt to be greatly increased with the rapid accumulation of dirt on the lamps and reflectors. These items will be clearer by a reference to Figs. 3 and 4, which compare free space with one filled with belting.

Typical ceiling constructions are shown in Figs. 5, 6, 7, and 8 as found in average shops. The arrangement of lamps should not be influenced primarily by the ceiling construction. Plans made up without regard to the ease of installation may sometimes be modified so as to yield equally satisfactory results, however, with a considerable reduction in first cost for installing, by taking into account certain features of the beams or girders.

Illumination Factors

The spacing distance of lamps is a first consideration. Experiments have shown, for example, that in certain office locations with moderate ceiling heights, a spacing distance not exceeding 7 ft. 6 in. is most advantageous. This results in a uniform illumination on the desks if the proper reflectors are used, and the light from a sufficient number of sources thus secured insures a diffusion of the resulting illumination. The directional features of the light are furthermore far superior to those cases where larger spacing distances are employed.

The spacing also governs the size of lamp to be used. As

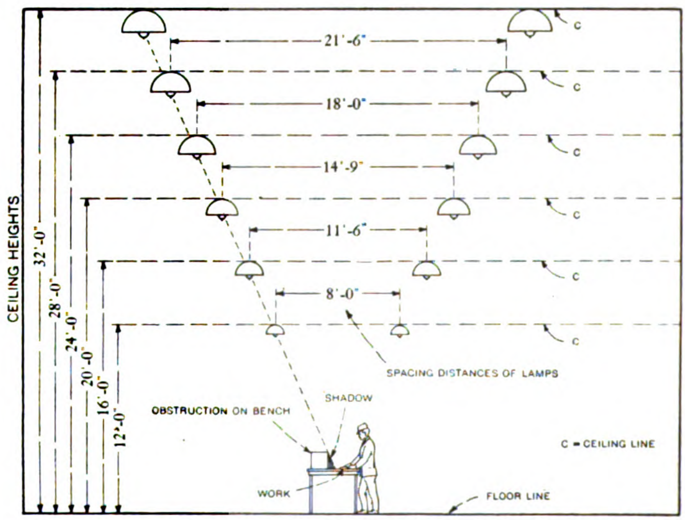


FIG. 9.—CHART SHOWING RELATION OF SHADOWS TO MOUNTING HEIGHT AND SPACING.

an illustration, whether one 250-watt or four 60-watt tungsten lamps are to be installed for a given area will be determined largely by the desired directional features of the light.

The mounting height should be determined on a basis of the avoidance of glare and of the ease in getting at the lamps for maintenance. The lamps should be mounted high enough to be out of the line of vision, and where the ceilings are too low to admit this, lamps of small size should be selected to reduce the quantity of light flux which enters the eye or is effective thereon when looking into any lamp. Fig. 9 shows the effect of height on the directional qualities of the resulting illumination

on the working surface. This illustration shows graphically the need of closer spacing to maintain a given minimum shadow effect for low ceilings.

Typical installations with accompanying data are indicated in Table I. Such a table of actual cases may serve as a guide to others with similar problems to solve, and also gives an idea of the varying requirements of different classes of industrial work from the fact that the installations here recorded have been the object of careful study for a number of years and furthermore are the results of carefully prepared plans. Obviously, these results are not intended to be used as rules for general lighting work, but the experiences recorded for these representative locations will show clearly how they have been solved and what constants apply in each of the several cases.

Efficiency of Utilization

The term efficiency is here used to express the relation between total light flux furnished by the lamps to the work, on the one hand, and the total flux emanating from the lamps of the system in all directions, whether useful or otherwise, on the other hand.

Such a use of the term refers of course to the efficiency of the lamps themselves coupled with surroundings and reflectors in the matter of the useful illumination they furnish to the work. The numerical values expressing this efficiency will thus be less than unity and expressed in per cent of the ideal condition if the total light flux available were wholly useful on the work.

Heretofore the measure of illumination efficiency, if it may be so called, has been changed in turn from watts per square foot required to furnish presumably satisfactory light, to lumens per watt (or foot-candles per watt per square foot), and finally to efficiency or the utilization of the total light flux of the lamps. The latter is a measure of the total losses from all causes, such as absorption by globes or reflectors, by dark ceilings and walls, as well as by dust, dirt, belting, or other obstructions, and therefore adapts itself in an excellent manner to practical usage. One other feature should be noted in connection with the efficiency, namely, the importance of considering average performance, in distinction to results obtained when lamps and reflecting devices are new and clean.

The need for data on the *average performance* of illumination systems has been felt for some time. With the view of meeting this need, and also for the purpose of establishing some certainty

TABLE I. DATA ON TUNGSTEN INDUSTRIAL LIGHTING SYSTEMS

Height of ceiling or girder line.	Mounting height above floor.	Rating of lamp.	Style of reflector	Class of work.	Spacing distance	Intensity in foot-candles.	Lumens per watt.	Efficiency of system. Lumens on working plane divided by total lamp lumens	Condition of reflectors.	Character of surroundings.
			General offices							Light ceiling and walls
10 ft.1¼ in.	9 ft.5¼ in.	60-watt	I Satin-finish prismatic	Office	5 ft.8 in. by 7 ft.9 in.	3.9	2.85	34.4	Clean	" " " "
10 ft.8 in.	10 ft.0 in.	60 "	F " " "	"	7 ft.0 in. by 7 ft.4 in.	3.6	3.1	37	"	" " " "
10 ft.8 in.	10 ft.0 in.	60 "	I " " "	"	6 ft.3 in. by 6 ft.10 in.	4.4	3.08	35.8	"	" " " "
10 ft.8 in.	10 ft.0 in.	60 "	F Clear prismatic	"	5 ft.7 in. by 7 ft.4 in.	3.2	2.19	26.5	"	" " " "
10 ft.10 in.	10 ft.2 in.	60 "	I Satin-finish prismatic	"	5 ft.9 in. by 7 ft.3 in.	4.5	3.14	37.8	"	" " " "
10 ft.10 in.	10 ft.2 in.	60 "	I " " "	"	5 ft.1¼ in. by 6 ft.9 in.	3.7	2.06	24.8	Slightly soiled	" " " "
13 ft.0 in.	11 ft.6 in.	60 "	F " " "	"	6 ft.6 in. by 6 ft.10 in.	4.3	3.17	38.2	Clean	Dark walls and ceiling
15 ft.0 in.	12 ft.10 in.	60 "	I Opalescent	Drafting	8 ft.3 in. by 9 ft.6 in.	7.2	2.34	28.2	Slightly soiled	Rather dark walls and ceiling
			Factory offices							
8 ft.9 in.	8 ft.0 in.	60-watt	I Opal	Office	6 ft.0 in. by 7 ft. 6 in.	4.25	3.17	38.3	Clean	No ceiling—fairly light walls
9 ft.0 in.	8 ft.6 in.	60 "	I Clear prismatic	"	5 ft.7 in. by 5 ft. 9 in.	2.9	2.75	33	Fairly clean	" " rather dark "
11 ft.6 in.	10 ft.9 in.	60 "	F " "	"	5 ft.7 in. by 7 ft. 1 in.	5.4	3.47	42	Clean	Light ceiling-glass partitions
13 ft.9 in.	13 ft.9 in.	60 "	F " "	"	5 ft.4 in. by 5 ft. 7 in.	3.5	1.75	21	"	" " light walls
16 ft.0 in.	14 ft.0 in.	150 "	F " "	"	8 ft.2 in. by 9 ft. 0 in.	4.5	2.22	26.7	"	" " glass partitions
16 ft.0 in.	10 ft.0 in.	60 "	I " "	"	7 ft.0 in. by 7 ft. 6 in.	3.5	3.07	37	"	" " " "
			Factory space							
8 ft.1 in.	7 ft.6 in.	60-watt	I Opal	Factory	8 ft.0 in. by 8 ft. 0 in.	3.2	3.42	41.1	Clean	Light ceiling—no walls
11 ft.9 in.	11 ft.0 in.	100 "	I Clear prismatic	Machine shop	8 ft.0 in. by 8 ft. 9 in.	4.3	2.74	33	"	Dark " —dark walls
12 ft.6 in.	12 ft.0 in.	100 "	I " "	" "	8 ft.0 in. by 10 ft. 0 in.	3.1	2.46	29.6	"	" " —No "
13 ft.6 in.	9 ft.0 in.	150 "	I " "	" "	8 ft.0 in. by 8 ft. 6 in.	6.6	2.98	35.9	"	" " —Dark "
13 ft.9 in.	13 ft.0 in.	100 "	I " "	Factory	8 ft.0 in. by 8 ft. 0 in.	3.2	2.02	24.3	"	Light " —Light "
13 ft.9 in.	13 ft.0 in.	100 "	I Opal	"	8 ft.0 in. by 8 ft. 0 in.	3.8	2.40	29	"	" " — " "
13 ft.9 in.	13 ft.0 in.	100 "	I Clear prismatic	"	8 ft.0 in. by 8 ft. 0 in.	3.8	2.40	29	"	" " — " "
24 ft.9 in.	21 ft.3 in.	250 "	F " "	Power house	12 ft.0 in. by 15 ft. 0 in.	2.7	1.92	22	Soiled	" " — " "

regarding the various factors involved, extensive tests have been conducted during the past year, and the results of the same are now herewith presented for the first time in the hope that they may furnish useful information on this important phase of illumination systems, and also serve to further additional work, thus begun in this particular direction.

Practical Results under Working Conditions. At the outset a study was made of the items involved in the determination of the average performance, that is, the variation in the illumination intensities furnished by the lamps day in and day out, and a number of typical locations representative of average industrial conditions were selected for the test. These tests were made on the vertically downward (or so-called horizontal) intensities of the illumination produced by a fairly large number of lamps in each location, thus securing a more general idea of the changing conditions than would likely result from individual tests on single lamps or reflectors. By these tests it has been sought to establish the actual efficiency of the various illumination systems considered, as compared to the theoretical efficiency which might be supposed to exist from calculation based on candle-power distribution curves. Four conditions were chosen as follows: (1) new lamps and reflectors; (2) clean lamps which have been in service for several months, and clean reflectors; (3) clean lamps several months old and soiled reflectors, ready to be washed in the routine of the plant; and (4) soiled lamps and soiled reflectors ready to be cleaned. This series of conditions represents lowering steps in the efficiency of the system, and the results show by how much each of these factors may reduce the total efficiency. It will be apparent that the reduction in efficiency by these three items refers to losses in the system itself. These losses further obviously determine the inherent performance of the system, and great care was required in making these tests to maintain conditions unchanged throughout the tests, that is, under shop conditions, to be sure that the dust and dirt on reflectors was left undisturbed.

Five typical factory locations were selected for this test, which covered seventeen weeks in itself, but which represents a considerably longer period of time in preliminary tests made throughout the past few years leading to the determination of ultimate reductions of light due to dust and dirt. These five locations were equipped with tungsten lamps and glass reflectors. The locations included a regular office in an office building; a long

narrow factory office ; a low factory space with no walls and very dark ceiling; a medium high factory space with light walls and light ceilings; and a moderately high factory space with dark walls and no ceiling, the lamps being mounted on stringer boards attached to the girders. Observations of voltage were taken and all intensities corrected for the normal lamp voltage. Table II shows the results of these tests and the attending surrounding circumstances, while Table III shows the averages of the results. The value of these constants can hardly be overestimated when

TABLE II
TEST RESULTS ON TUNGSTEN SYSTEMS WITH GLASS REFLECTORS.

Efficiency values* / Conditions of test	Low office	Fairly high factory office	Low factory space	Medium high factory space	Fairly high factory space
Ceiling	Light	Light	Dark	Light	None
Wall	Light	Light	None	Light	Dark
Lamps	60-W Cl.	60-W. Cl.	100-W. Cl	100-W. Cl	100-W. Cl
Reflectors	I-60 SF.	I-60 Cl.	I-100 Cl.	I-100 Cl.	F-100 Cl.
Class of work	Desk	Desk	Machines	Bench	Bench
Time between washings	14 weeks	17 weeks	9 weeks	11 weeks	13 weeks
Results		Efficiency	in per cent		
Soiled lamps Soiled reflectors	19.7	24.2	22.4	25	20.1
Clean lamps Soiled reflectors	20.7	24.9	22.5	27	23.6
Clean lamps Clean reflectors	34.1	29.3	31.2	35.3	33.6
New lamps Clean reflectors	34.1	31.2	31.9	36.1	39.1

*All efficiency values corrected for normal lamp voltage.

considered in the light of their usefulness in the calculation of factory lighting systems, which can thus be based on absolute experience. The foregoing notes apply to the performance of a system as installed and in regular service.

Depreciation Items. In the calculation of illumination systems additional factors must be taken into account, namely, (1) the effect due to the operation of the lamps at a voltage other than the irrating, frequently the case in tungsten systems; (2) the depreciation of candle power due to the aging of the lamps; (3)

the depreciation due to surroundings which are liable to become dark; and (4) the effect of dust and dirt accumulations.

The losses due to ***voltage*** conditions can readily be calculated from the curves showing the variation of candle-power with voltage; the effect of ***age*** of the lamps, although somewhat more uncertain, can be determined with a fair degree of accuracy from the life curves of the lamps as made by the lamp manufacturing companies; tests have been conducted, as previously referred to, in the determination of the effect of ***surroundings*** on the illumination results. The following material has resulted from extended tests on a variety of lighting systems to determine the dust and dirt characteristic depreciation curves with elapsed time of service. While the tests just described for the determination of practical efficiencies at the beginning and at the end of a cleaning

TABLE III

AVERAGE TEST RESULTS ON TUNGSTEN SYSTEMS WITH GLASS REFLECTORS*

	Average efficiency of system
Low office	27.1 per cent
Fairly high factory office	27.4 " "
Low factory space	27 " "
Medium high factory space	30.8 " "
Fairly high factory space	29.1 " "

*All efficiency values corrected for normal lamp voltage.

period were difficult in the matter of maintaining conditions unchanged, these same difficulties encountered in this particular test were considerably greater. To insure value, it was deemed essential to perform the tests in factory spaces where the regular manufacturing operations were in progress from day to day. This necessitated constant watchfulness to make sure that the systems were undisturbed in the matter of the dust and dirt accumulations.

At the outset the results anticipated rather seemed to promise indefinite results. Figs. 10, 11, 12, 13 and 14 indicate the characteristic curves of illumination intensities over a number of weeks as the result of the tests, and from these curves the very interesting and instructive conclusions may be roughly drawn, that under average factory conditions the deterioration of glass reflectors due to dust and dirt follows a fairly definite rate of

candle power reduction, in so far as conclusions can be deduced from the number of cases on which these tests were conducted. This reduction as shown in the curves is due alone to dirt accumulations on the reflectors, since the new lamps were inserted before each test and all observations were corrected to correspond to normal lamp voltage.

The curve sheet shown in Fig. 15 has been derived from the deterioration curves. This curve sheet shows, for example, that based on the average cleaning cost of three cents per reflector, with energy at two cents per kilowatt-hour, the integrated cost of light lost at the end of sixteen days in one of the cases, is equal

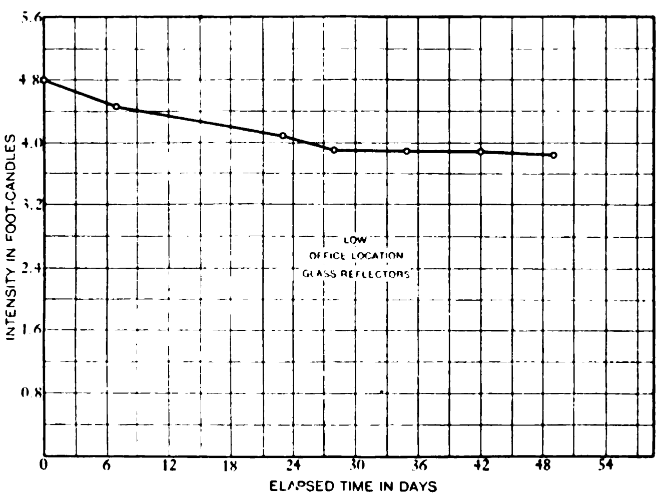


FIG. 10.—DETERIORATION FROM DIRT ACCUMULATIONS.

to the cost of cleaning. This point (namely sixteen days) would then naturally determine the economical interval for cleaning reflectors in this particular location, provided always that the reduction in intensity at the end of this interval is not below that which is necessary for satisfactory vision. It is of interest to note that apparently the effect of dust and dirt takes place far more rapidly in the first week or ten days than during the succeeding weeks.

Other useful information may be deduced from these curves as follows; if, for example, the loss of light at the end of sixteen days equals 25 per cent, which means, for an initial intensity of four foot-candles, that there remain, at the end of sixteen days,

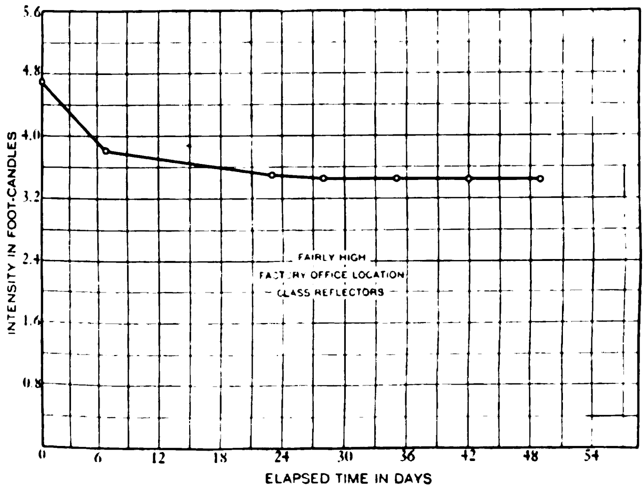


FIG. 11.—DETERIORATION FROM DIRT ACCUMULATIONS.

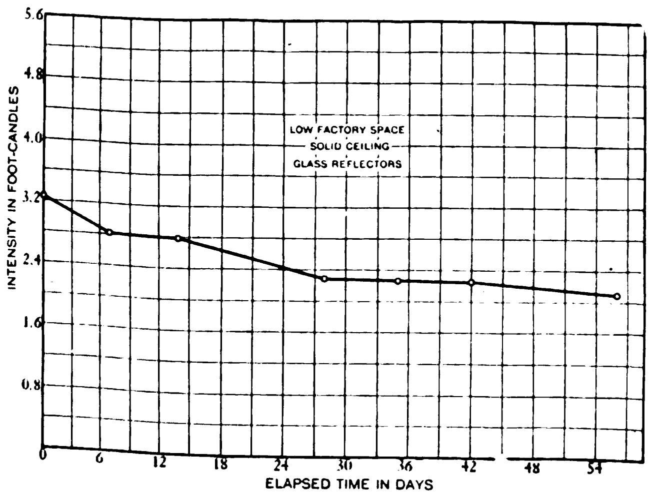


FIG. 12.—DETERIORATION FROM DIRT ACCUMULATIONS.

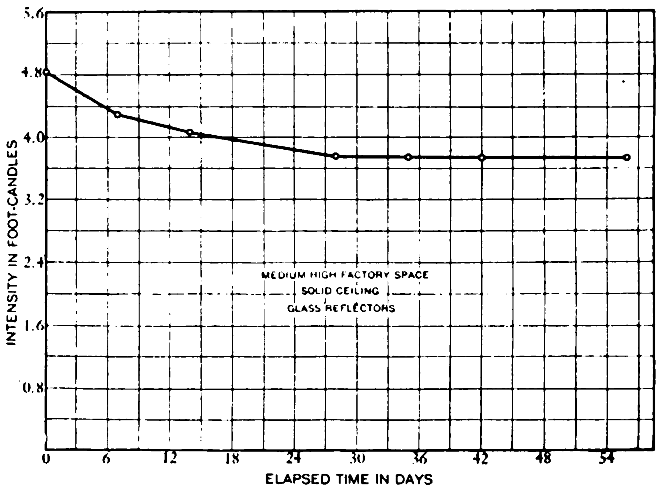


FIG. 13.—DETERIORATION FROM DIRT ACCUMULATIONS.

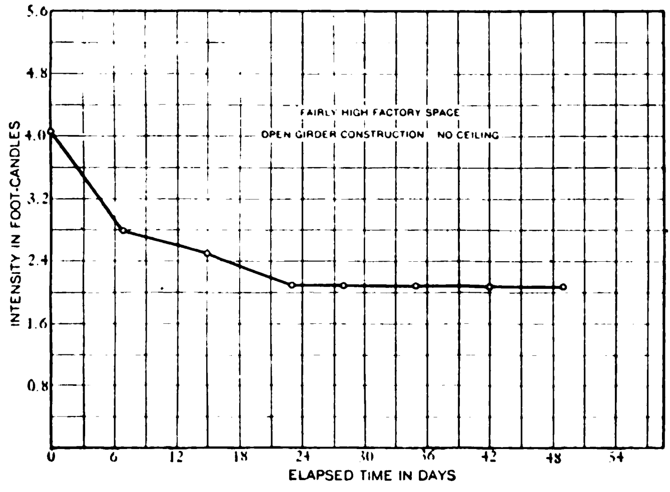


FIG. 14.—DETERIORATION FROM DIRT ACCUMULATIONS.

only three foot-candles, the average intensity throughout the sixteen day interval may be approximated at three and one-half foot-candles, provided the reflectors are cleaned once every sixteen days.

If an additional sixteen days without cleaning means a still further reduction from three to two foot-candles, the average intensity of the illumination throughout the thirty-two days interval may be approximated at three-foot candles. Hence the cleaning of the reflectors at intervals of sixteen instead of thirty-two days should insure an average intensity of say three and one-half instead of three foot-candles, or in other words to main-

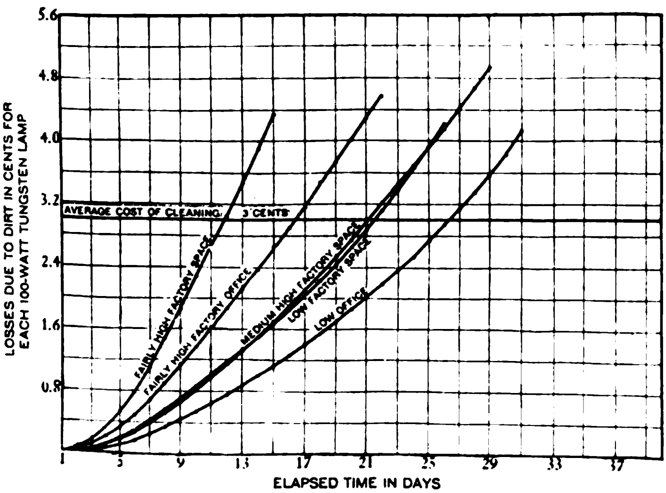


FIG. 15.—SUMMARY OF CURVES OF DETERIORATION COSTS FROM FIGS. 10, 11, 12, 13 and 14.

tain an average intensity of three and one-half foot-candles would require approximately twenty per cent more lamps in the installation for a thirty-two days than for a sixteen days cleaning interval.

This would mean in an installation of say 1,200 tungsten lamps, a saving of 200 lamps in the original installation, or roughly, $1,000 in a total of $6,000, the first cost, by the adoption of a sixteen days instead of a thirty-two days cleaning interval. To clean 1,200 reflectors every thirty-two days involves in practise an expenditure of approximately $432 per annum, while to clean the smaller number of 1,000 reflectors once per sixteen days involves approximately $720 per annum, or an

increase of say $288 per annum. The increased cost of cleaning, with shorter cleaning intervals, is, therefore, small in comparison to the reduced first cost, to the lower energy consumption with a smaller number of lamps, and to the improved average service.

The foregoing hypothetical instance can be worked out with accuracy for any of the locations found in the deterioration curve sheets, by the substitution of actual for the assumed values, and when applied to practical illumination design will be found to affect the results in a significant manner.

MAINTENANCE

Necessity for Systematic Maintenance. From the foregoing statements the necessity for careful and systematic maintenance will at once be apparent. In one large system of 10,000 tungsten lamps, the losses of light per day due to dust and dirt interpreted into money values, that is to say, evaluating the energy in watts represented by light wasted through absorption by the dirt, to its kilowatt-hour cost, amounts approximately to $20 per day, or $7,500 per annum. If the systems are allowed to go uncleaned beyond the economical point, these losses become aggravated. The expenditure of an amount like the foregoing, for energy which represents no return, serves to indicate in a startling manner the significance of adequate maintenance.

This illustration and the ones previously mentioned in connection with deterioration have been based on tungsten systems, but the results will show what may be expected in lighting systems of other types of lamps from the accumulation of dust and dirt, and it is hoped that these tests and statements will be but forerunners of additional data along these and similar lines in the near future.

General Methods. The limitations of this paper prevent more than a passing reference to the details of maintenance work. It will suffice to say that systematic methods are now being worked out and are in operation for handling this feature of lighting system operation. It is the desire that data like the foregoing will be a stimulus to further and more liberal attention in the matter of such work, and that they will promote more system in short cleaning intervals and other similar work.

ECONOMIC RELATIONS

Relation of Wages to Illumination. The chart shown in Fig. 16 has been prepared to give an idea of the relation of average wage

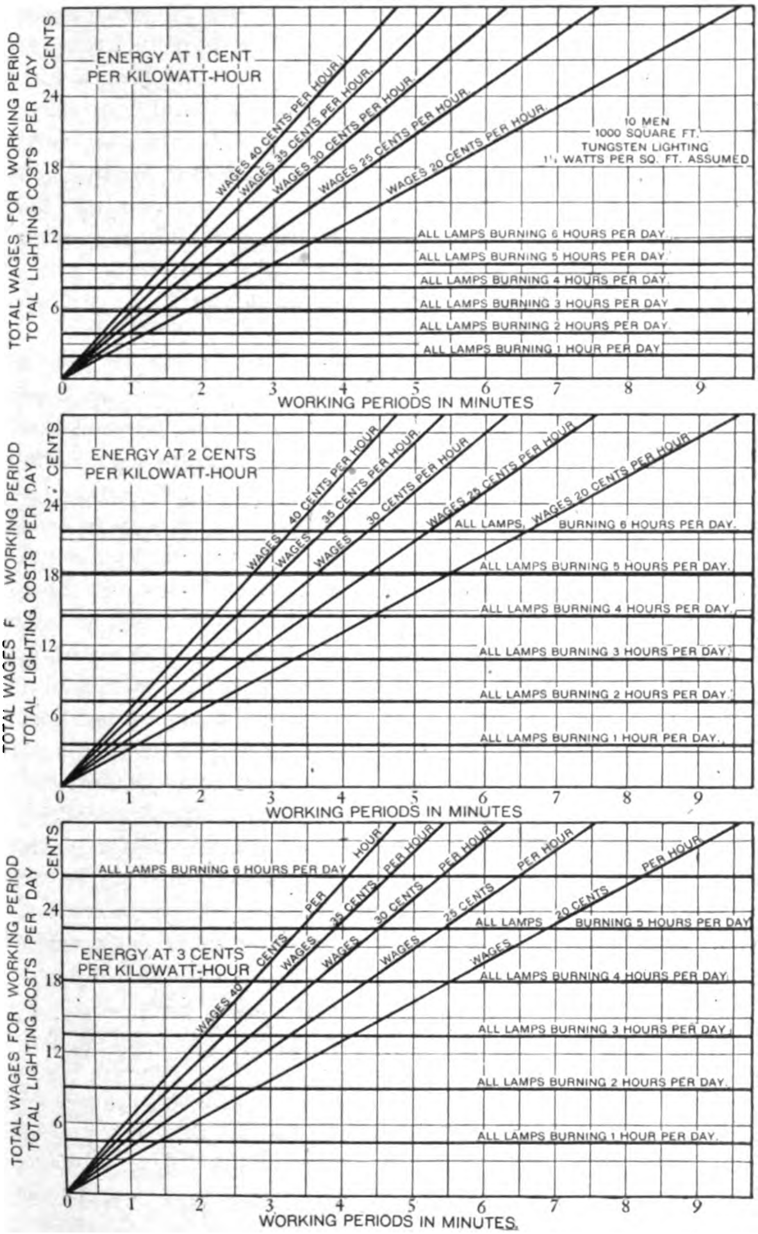


Fig. 16.—Curves Showing Relation of Average Wages to Lighting Costs.

conditions and lighting costs. The values are taken from actual average cases and show in a graphical manner the small percentages of the total wages represented by the average lighting costs. When one pauses to consider the fact that the wages for six minutes per day in average shops, pays not only for meagre, but also for entirely adequate illumination, and when one further considers that nearly all shops have some lighting facilities, poor as they may be, the difference between poor and excellent lighting in its relations to improved surroundings and better workmanship is apparent.

Present Activity in Industrial Lighting

In one large shop where extensive installations of high efficiency lamps have been under way for nearly three years, a summary shows an increase of nearly 30 per cent in actual candle power for a 5 per cent increase in total operating and maintenance costs. This increase of 30 per cent in candle power in no way, however, indicates the enormous improvements in the matter of excellence in distribution and refinement of results; it merely shows what great advances have been made in the possibilities of industrial illumination by the newer types of lamps. Added to this candle power increase there are, of course, many advantages which have been brought about by the careful and scientific adaptation of the lamps best suited to each condition.

It will be impracticable to indicate in a definite manner the extent of present activity in terms of exact installations, but it is of both interest and significance to note the progress which is being made in the growing intelligence among factory owners regarding the proper illumination for their plants. The work of the past few years along this line, if taken as an indication of what may be expected, promises great advances in the immediate future.

A paper presented at the 29th Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June 27, 1912.

HISTORY AND DEVELOPMENT OF SUBMARINE SIGNALING

BY H. J. W. FAY

In former times every ship that went to sea was in danger of foundering or being driven ashore in a storm; of being destroyed by fire or disabled and lost through an accident to her machinery. She ran the risk of collision with an iceberg, a derelict or another ship, and of running ashore in darkness or thick weather.

Through the progress of marine engineering storms are no longer a serious menace and fires and accidents to the machinery seldom result in the loss of the ship. Derelicts are systematically hunted down and destroyed. Icebergs by changing the temperature of the air and water often give their own warnings, but are always a menace to navigation. The careful charting of the coasts together with the use of lights at dangerous points have rendered insignificant all other risks except those due to fog. In thick weather the lights become useless, accurate observations are impossible and fog horns are tricky and unreliable. Without warning a ship may run ashore or collide with another vessel.

In an attempt to remove this danger to navigation millions of dollars have been spent on fog horns and other devices for sending sound through the air, but the results have been most unsatisfactory owing to the fact that air does not transmit sound uniformly. It varies in density and columns and bodies of air at different densities reflect and refract sound so that when heard it may not truly indicate the direction from which it comes and it often skips over spaces where it cannot be heard at all.

In illustration of this point, from 1893 to 1902 between 900 and 1000 vessels were wrecked by aberrations of sound or by

being drawn on a false course by the echo. The approximate loss in property amounted to $57,500,000.00, and no less than 530 human beings were sacrificed. These statistics became an appeal from the mariner and encouraged inventors to renewed efforts which were at last realized in a successful system of submarine signaling.

Following the progress of submarine signaling from its beginnings to its present state of perfection, we find that this invention was not the inspiration of a single mind but a consistent development to which many workers have at different times contributed.

Much of the pioneer work in the early stages of submarine signaling did little more than to furnish a basis for the later more successful work.

In tracing the history of any successful invention it will be noted that three separate and distinct stages mark its development.

1. The discovery of the basic principle or fact upon which the invention rests.

2. The invention and development of ways and means for carrying this principle into practical effect.

3. The development and reduction of the invention to practical and commercial use.

The fact upon which submarine signaling is based is that water is an excellent conductor of sound. Submarine signaling, as the name denotes, is the art of transmitting sound through water. In telegraphy and telephony wires are used as a medium to transmit energy from one point to another. In wireless signaling we understand the ether is the medium by means of which energy is transmitted. In submarine signaling the medium for the transmission of energy from one point to another is water.

The art of submarine signaling may be roughly divided under two heads, namely, the sending of signals through the water and the receiving of signals sent through water.

Before attempting to describe in detail the apparatus which has been developed and is now being used for sending and receiving submarine signals, I will outline briefly the history of the art. Let us first take up the basic facts upon which the whole theory of under-water signaling has been built and see if we can determine when the principle that sound could be transmitted through water was first discovered. We find abundant references to the art of water signaling if we but look for them.

It has not only been a matter of common knowledge for ages

that sound would pass through water, but also that it would travel through water and pass through the side of a ship so as to be heard by an observer stationed below the water line.

If the truth could be known, it would doubtless be found that primitive man made use of some form of water signaling, however crude and inefficient his instruments may have been. It is said that the natives of Ceylon used this knowledge a very long time ago to signal each other when at sea in their fishing boats, using an earthen "chatty" which they submerged and struck, thus producing a sharp percussive clink that could be heard by placing the ear against the bottom of a boat miles away.

In 1826 we find a record of the fact that two scientists, Messrs. Colladon and Sturm, wanted to ascertain the velocity of sound in water. They did what they no doubt considered a commonplace and obvious thing to do, that is, they struck a submerged bell with a hammer and listened for the sound produced by submerging in the water one end of a common ear trumpet and holding the other end to the ear. It is quite possible they knew of certain experiments in the transmission of sound under water made in 1767 by a Scottish scientist who submerged his head in the waters of a lake near Glasgow and heard a large hand bell, also submerged, at a distance of 1200 feet.

There is no reason to believe, however, that in constructing their simple apparatus they did more than apply their knowledge of well-known facts. They evidently had no thought of applying this knowledge to the working out of a system of submarine signaling; they were interested simply in the study of the relative velocity of sound in air and water. They used for their own purpose the same instruments that were subsequently used for quite different purposes.

These instances merely illustrate that water signaling was a matter of common knowledge long before any one attempted to patent and develop the system of submarine signaling which has come into general use and is now known the world over. It will thus be seen that in reviewing the first stages of the development of submarine signaling we are not able to fix definitely the date of the discovery of the principles upon which the present-day system has been built.

In tracing the second stage of the development of submarine signaling we find the first published record of any attempt to apply the fundamental principles of water signaling to a regular system of submarine signaling to be embodied in an English

patent issued to Mr. Henry Edmunds in 1878. The Edmunds patent outlined in a crude way a method of ringing an electric gong under water, and also a method of attaching a bell to a bell buoy and allowing the swaying motion produced by the movement of the buoy to throw the clapper against the bell. It also suggested in rather vague and general terms that sound could be created under water by submerging and energizing an ordinary telephone receiver. These three sound producers have since been proved entirely inadequate. For receiving apparatus, Mr. Edmunds proposed using an oar with its blade submerged in the sea and the end of its handle pressed against the ear. He also suggested that an ordinary telephone transmitter might be submerged so as to pick up the sound from the open sea, but gave no details as to the construction of the instrument. His scheme was all on paper and so far as he was concerned never seems to have gone beyond that stage. Still we must, in all fairness, give Mr. Edmunds credit for outlining in his patent the general scheme for a system of sending and receiving submarine signals. The real problem, however, of carrying this system into practical effect was left to be solved by others.

Nine years later, Mr. William G. Spiegel obtained a U.S. patent for a submarine sending and receiving system. He claimed the use of a metallic sounder percussively struck outside a ship for a sound producer and for receiving apparatus a pneumatic tube piercing the bottom of the ship and open to the sea at its lower end, with an ear piece on the upper end for the observer to listen for the sound. Just above the sea level in the tube he provides a diaphragm with connections to an electric call bell. He expected that the sound waves coming up the tube would provide energy enough to ring the signal bell, but this type of receiving apparatus was found inefficient and impracticable.

The following year, 1888, Messrs. Neale and Smalpage, in England, applied for a patent, in which they described a telephonic diaphragm covering and closing a hole cut in the side of a ship. Against this diaphragm inside the ship they proposed to place a make-and-break microphone in circuit with a telephone receiver, or if preferable, an air chamber connected with an ordinary speaking tube having an ear piece at the upper end; thus the sound from the sea was to be picked up by the diaphragm, and would be transmitted to the ear of the observer either electrically or pneumatically.

Neale also proposed the use of microphones on the outside of the ship below the water line. For practical use there were obvious objections to putting the apparatus on the outside skin of a ship, and his invention embodying the idea of cutting a hole in the ship's side below the water line to be covered by a thin diaphragm would not work out well. Neither of his inventions seem to have gotten beyond the patent stage.

One year later, in October, 1889, Professor Lucien I. Blake was granted a patent for a pneumatic form of receiving apparatus practically the same as that shown in the English patent to Messrs. Neale and Smalpage, the year before. Professor Blake also proposed the use of the water siren for producing sound signals. This is one of the forms of sending apparatus to which a great deal of time and study are being devoted at the present time. Although Professor Blake did not apply for a patent until 1889, he first conceived the idea of a submarine signaling system in 1883, it being suggested to him by the experience of Messrs. Colladon and Sturm in 1826.

Apparently the invention of the telephone in 1876 stimulated a number of inventors to reattack the subject of submarine signaling, for between 1876 and 1891 we find independent effort being made in many quarters of the globe. Among others, A. Benari of France; Mario Russo d'Assar of Italy; Thomas A. Edison, William G. Spiegel, John M. Batchelder, Lucien I. Blake, E. Huber, and F. J. Kneuper of the United States; Henry Edmunds, F. N. Boyer, N. T. Neale, J. H. Smalpage, Walter Walker, and others of England.

After the above mentioned inventors had exhausted either their ingenuity or their resources, a period of several years elapsed without anything happening. The net result of all effort *prior to* 1898 was simply this—a system of submarine signaling was evidently possible, but the apparatus which would make it commercially available had not yet been invented.

In May, 1898, the late Arthur J. Mundy of Boston took up the development of the system of submarine signaling and finally carried it to that point of perfection where it could be adapted to commercial use. He realized that the crude idea of transmitting sound signals under water would have little value unless backed by expert knowledge, business ability, and financial strength, and proceeded to form a syndicate for developing the invention, thus entering upon its third stage of commercial development.

He communicated his idea to Professor Elisha Gray, who immediately joined him in experimental work at Mr. Mundy's seashore residence on Cape Ann, Mass. Professor Gray, with his general knowledge of acoustics and experience with the telephone, was sanguine of speedy success. But after many costly experiments it was found in March 1899 that the real problem was still unsolved and that much additional time and money would be needed to develop the system.

At this juncture Mr. Mundy was joined by Mr. J. B. Millet, a former business associate, who in turn secured the interest and financial backing of his friend Mr. Henry M. Whitney.

It was then deemed expedient to organize a company and this was done in 1899. For this company Professor Gray and Mr. Mundy carried on the submarine signal development work continuously until January 1901, a period of nearly three years, when Professor Gray's sudden death left the development of the system in the following condition:

A bell struck under water was heard a considerable distance through a submerged telephone transmitter. The submerged transmitter was lowered over the ship's side in a calm sea, the ship being motionless and noiseless. Both the sound producing and sound receiving apparatus were complicated and clumsy and not adapted for commercial use.

There was no apparatus which could be installed within the ship and heard a sufficient distance, and no receiver which would not be rendered useless by the noises of a moving ship. No means of determining the direction of the source of sound had been discovered.

Therefore, the problem which presented itself at the time of Professor Gray's death in January 1901, was to *find the direction of the signal,* on a *moving vessel,* in any sea.

The key to the entire situation was discovered by Mr. Mundy.

The solution lay in the use of an all-water system of submarine signaling and consisted of a microphone in a tank of water one side of which was formed by the skin of the ship below the water-line. The water on both sides of the skin forms a practically continuous path from the bell to the microphone.

This discovery made it possible to hear the signals on a vessel moving at full speed in any sea without being confused by the other or foreign noises. It is the only method which removes the foreign noises and at the same time preserves the strength of the signal.

It only remained to design microphones adapted for use in the tank and to develop a method of finding the direction of the bell. The latter was accomplished by means of two tanks one on each side of the ship near the bow, and was patented by Messrs. Mundy and Millet on August 20, 1894.

At the same time that the receiving apparatus was being developed, good progress was being made in perfecting the sending apparatus so that it would be adaptable to commercial service on lightships, bell buoys and electric cable shore stations.

It was deemed expedient shortly after Professor Gray's death to incorporate a new and larger company to buy out the old company, and the new company was incorporated in September, 1901. The financial status of the enterprise was strengthened by the accession of many new stockholders, thus accomplishing the third stage of development so essential to the success of any invention, and placing the company in a position to extend the system to all parts of the world.

Development of the Sending Apparatus

The very first sound producers tried were 120-lb. bells of the common locomotive type with a rate of 320 vibrations per second.

These were electrically excited first with pulsating current and later with alternating current. Then larger bells of 300 pounds were tried with a rate of about 400 vibrations per second. Some of these were made of bell metal and some were made of steel and were excited electromagnetically with an alternating current.

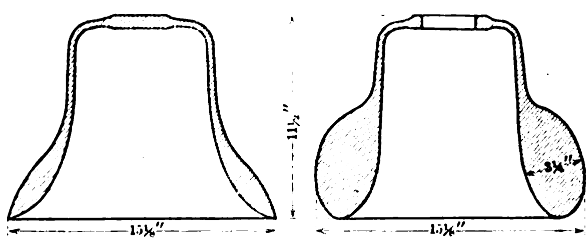
With these bells numerous tests were made with the U. S. lighthouse tender *Mayflower* on *Boston Light-Vessel*, and they were heard at varying distances of from one to three miles.

The percussive means of exciting bells was then tried. Numerous experiments were made to determine the weight and shape of the striking hammer. The weight, shape and period of the bell were also undergoing changes as the experiments progressed. A series of tests and experiments finally developed a bell weighing 220 pounds with a period of 1215 vibrations in water. This type is now being used universally and is adaptable for use on light-ships, electric shore stations, and bell buoys. Fig. 1 shows the submarine bell in cross section as compared with an air bell of the same size.

For Light-Ship Work. After trying electric, hydraulic and steam power to operate the mechanism in striking the submerged bell, the present pneumatic bell was designed by Mr. E. C. Wood, who was associated with Professor Gray, Messrs. Mundy and Millet in all their early experiments, and carried forward the work from the point at which it was dropped by them to its present state of perfection.

Development of Receiving Apparatus

The first boat on which submarine signal receivers were installed was the *U. S. R. C. Seminole.* Tests were made with this ship in Boston Harbor but the boat was not under way. The bell was operated one-half mile away and was an 800-lb. church bell with a rate of about 450 vibrations per second.



Air Bell.
Weight 85 lb.
Vibrations per sec. 350.

Submarine Bell
Weight 210 lb.
Vibrations per sec. { in air 1280 / in water 1215

Fig. 1.—Sketch Showing Difference between Air Bell and Submarine Bell.

The next boat equipped was the *Cape Ann*, a steel passenger boat running between Boston and Gloucester. This was the first boat on which tests were made with the vessel under way. The signal station used in these tests was an electrically operated bell at Egg Rock. With the *Cape Ann* at half speed this bell was heard at a distance of three-quarters of a mile.

The next vessel to be equipped with submarine signals was the *Chippeta*, a wooden ship which was used as an experimental boat. Many different forms of receiving apparatus were tried on this boat; holes were cut through the vessel's skin and thin diaphragms were placed in the side of the vessel underneath the water line with microphones mounted directly on them.

Installations were also tried with the receiving instruments in direct contact with the skin of the vessel but were found

to be inefficient for commercial use, especially when the vessel was under way, owing to the interference due to the vibrations set up in the vessel itself by the machinery and by the impact and rush of water past the ship's sides. These are commonly called foreign noises and are very hard to eliminate.

Air and gases were also tried as a transmitting medium to convey the bell sound from the vessel's plate to the receiving instruments and were found to be inefficient in comparison to liquid. The tank method of installation was finally settled on with liquid as the medium of transmission between the ship's plate and the receiving instruments.

The next experiments were conducted on the *James S. Whitney*. Wooden tanks were constructed in her fore-peak, using the outer skin of the vessel for one side of the tank. They were very large, containing about 64 cubic feet of water. By the time this ship was equipped with receiving apparatus, Boston Light-Vessel had been fitted with a steam struck bell. This bell was an improvement on the former bells, although it was not so large. It weighed about 120 lb. and had a period of 850 vibrations.

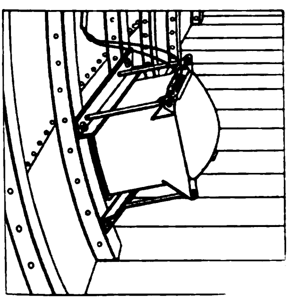


FIG. 2.—RECEIVING TANK.

Boston Light-Vessel bell was heard by the *James S. Whitney* at a distance of from ten to fifteen miles with the vessel steaming at fifteen knots and actual direction was obtained. This demonstrated the merits of the system.

The next step to be taken was to see if this type of installation could be generally applied to ships. It was found that the size and construction of the tanks on the *Whitney*, while all right experimentally, were not commercially adaptable.

The next development was to construct tanks which could be readily placed on any ship and give good results. After much experimental work the tank finally adopted was 16 in. square and 18 in. deep with a rubber gasket to make it watertight and to give it acoustic insulation from foreign noises in the vessel. The whole Metropolitan fleet was then equipped with the receiving apparatus.

The *Tunisian* of the Allan Line was the first transatlantic vessel to be equipped with submarine signals.

THE EQUIPMENT OF A VESSEL WITH SUBMARINE SIGNAL RECEIVING APPARATUS

To illustrate the method of installing submarine signal receiving apparatus on vessels, Figs. 3, 4 and 5 show the exact location of the most important part of the receiving apparatus, that is, the receiving tanks, on three types of vessels which vary greatly as to type and shape.

Fig. 3 shows the *Olympic* of the White Star Line. It will be noted that in this vessel the receiving tanks are located 74 ft. aft of the stem and 32 ft. below the water line.

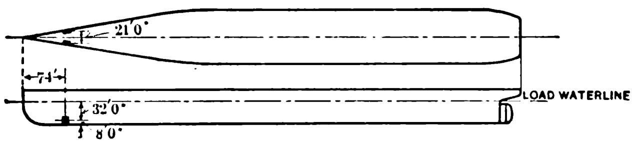


FIG. 3.—"OLYMPIC."

Length 882 ft.—Beam 92 ft.—Draft, loaded, 40 ft.; light, 20 ft.—Tonnage, 45,000.

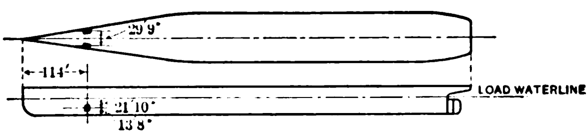


FIG. 4.—"MAURETANIA."

Length 790 ft.—Beam 88 ft.—Draft, loaded 35½ ft.; light, 29½ ft.—Tonnage, 32,500.

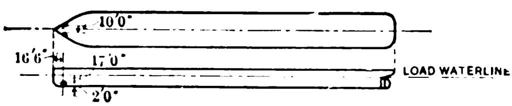


FIG. 5.—"J. P. MORGAN."

Length, 600 ft.—Beam, 58 ft.—Draft, loaded, 19 ft.; light, 7 to 16 ft.—Tonnage, 7161.

Fig. 4 shows the *Mauretania* of the Cunard Line. The lines of this vessel are very sharp as she is built for speed. Her tanks are placed 114 ft. aft of the stem and 21 ft. 10 in. below the water line in order to get the proper forward projection.

Fig. 5 shows the *J. P. Morgan*, a lake freighter. This type of vessel has a very bluff bow and it will be noted that the receiving tanks on this vessel have been placed a comparatively short distance of 16 ft. 6 in. aft of the stem and 17 ft. below the water line. If the tanks on the *J. P. Morgan* had been placed the same distance aft of the stem as those on the

Mauretania, that is, at a distance of 114 ft., this would have brought the *J. P. Morgan's* receiving tanks aft of her beam. The mouth of the receiving tanks would have had no forward projection and with the signal bell dead ahead no sound would be heard.

The installations on the above mentioned ships illustrate the point which I want to bring out, that in equipping a vessel with submarine signal apparatus the most important factor to be determined is the proper location of the receiving tanks on the vessel. In determining the proper location for the tanks the following points have to be taken into consideration.

The first consideration is that the tanks shall be placed on the inside of the skin of the vessel in such a position as to give them the greatest forward projection so that the bell may be heard as far as possible when the vessel is heading directly for the signal station.

The second point of importance is to locate the receiving tanks as far as possible below the surface of the water. The two conditions, the tank presentation and the depth, have a direct bearing on each other, and while it is of the utmost importance to get the tanks as far below the water line as possible this should not be allowed to interfere with the forward presentation.

Bow Waves. It is sometimes found after a vessel has been equipped, that the bow wave breaks near the place where the tanks are located and that by changing their position one or two frames forward or aft the water noise will be greatly reduced, and much better results obtained.

The installation of the rest of the system, the running of the cable, the installation of the water-tight junction boxes and the indicator box in the chart room or pilot house, is a simple matter. Owing to the excessive vibration on shipboard, however, it is necessary to use more than ordinary care in making up connections and the dampness and corrosion caused by sea air make it imperative to have all electrical apparatus moisture proof.

The Submarine Signal Apparatus

The apparatus used to-day divides itself into two classes; that which sends signals and that which receives them.

Sending Apparatus. The submarine bell on the light-ship or signal station is submerged and operated at a depth of not less than twenty feet under water. When struck its vibrations are sent out with equal intensity in all directions.

Of the sending apparatus there are four types at present in use; 1, pneumatic; 2, electric; 3, automatic; 4, hand.

For light-ships the pneumatic bell has been the most convenient form owing to the fact that many light-ships carry a store of compressed air.

For lighthouses and other places where a warning signal is desired and where there is no light-vessel and it is necessary to place the submarine bell at a distance from the shore, an electric bell has generally been used. By means of a cable from the lighthouse the power is conducted to a bell hung from a tripod on the sea bottom. An alternative type of apparatus for such a place is the automatic mechanism suspended from a buoy and operated by the motion of the waves. The rise and fall of the buoy winds up a spring which releases itself and strikes the bell a uniform blow.

At places too far removed from shore to permit running a cable, and where there is no light-ship, the bell buoy mechanism is the only one that can be used. So sensitive is it that even in an apparent calm it rings the bell several times a minute.

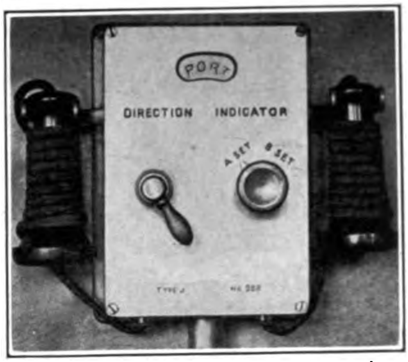
For the end of a breakwater or pier where a bell is needed to enable a vessel to enter a harbor or reach her berth, either the pneumatic or the electric bell may be used, the type of power most readily available being the deciding factor. For places where neither compressed air nor electricity is to be had, a hand bell can be used. In this, a spring is compressed and strikes a uniform blow.

For submarine boats either a pneumatic or an electric bell may be used and the same is true of submarine boat tenders and commercial ships.

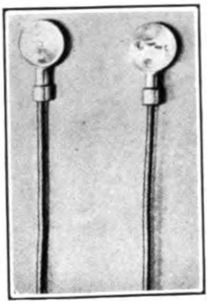
Receiving Apparatus. The receiving apparatus is made up as follows:

Two cast iron tanks are placed inside the ship against the skin, one on each bow. They are well below the water line and their distance from the stem varies from 20 to 150 feet according to the size and shape of the ship. They are filled with salt water and in each a microphone is suspended. Each microphone is connected with the pilot house or chart room by an electric telephone system. The bell sound coming through the water passes through the skin of the ship, enters the water in the tank and is picked up by the microphone which in turn transmits it to the pilot house. By means of an indicator box containing switches and arranged with two telephone receivers the observer can listen alternately

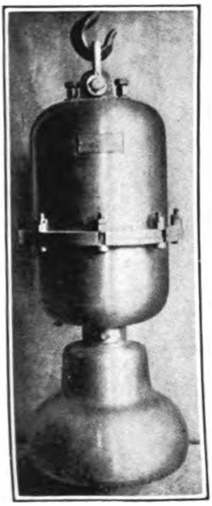
ELECTRIC BELL TRIPOD. [FAY]



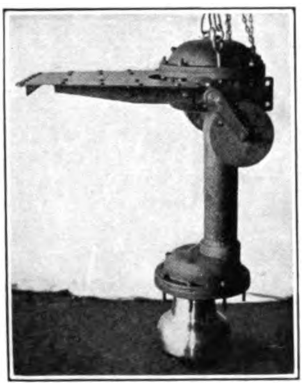
INDICATOR BOX. [FAY



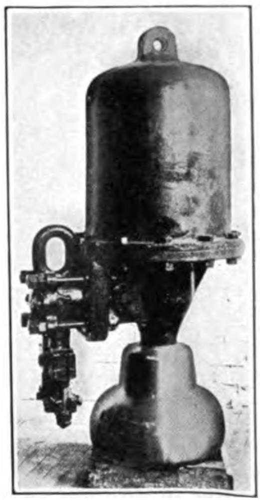
MICROPHONES. [FAY]



[FAY]
PNEUMATIC BELL.



AUTOMATIC [FAY
WAVE OPERATED BELL.



[FAY]
ELECTRIC BELL.

to the sound picked up by the port and starboard microphones. In practise two sets of microphones are used on each ship, one called the " A " set and the other the " B " set, one set being duplicate to the other.

The captains generally use both of the receivers when making an observation. This enables them to listen with both ears instead of only one, and it also shuts out other noises which may be disturbing. Many users of the apparatus at first have had the impression that one receiver is for listening on the port side of the vessel and the other on the starboard side. This is not so. Both receivers reproduce the same sound.

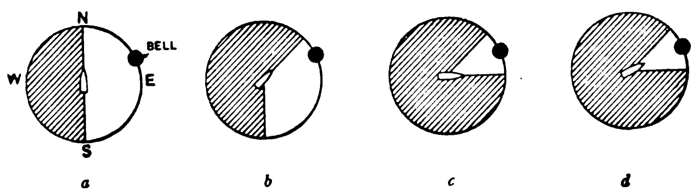


FIG. 6.—SUBMARINE SIGNAL DIRECTION FINDING.

These diagrams show how the direction of the bell may be determined on board ship by using the submarine signal receiving apparatus. Starting with ship heading north, with bell E. N. E.

a. Shows the ship headed north when the first observation is made. With the semaphore switch set to starboard the bell sound is heard, but with the semaphore switch set to port no bell sound is heard, showing that the bell is located in the unshaded portion of the circle.

(At distances less than one mile the sound may be heard faintly on the opposite side of the ship from the bell.)

b shows the ship swung to starboard four points, heading northeast, and the louder bell sound still being heard on the starboard side; the shading is extended, leaving only the small, unshaded portion of the arc to be explored. A faint sound may now be heard on the port side.

c shows the ship swung to starboard four points more, heading east, but in this position the louder bell sound is heard on the port side and the weaker bell sound on the starboard side, and the shading is again extended, showing that the ship has been swung past the bell, which now bears on the port bow.

d shows the ship swung two points to port, heading on the bell, in which position the volume, quality and tone of the bell will be equal on both port and starboard sides, showing that the bell is located dead ahead.

DIRECTION FINDING

The function of the sending apparatus is to produce a sound which is easily distinguished, that of the receiving apparatus to tell the direction from which the sound comes.

In Fig. 6 are shown the manoeuvers which would be executed by a captain in locating a bell.

To obtain the best results with the submarine signal apparatus it is necessary to make a careful study of the boat and the conditions under which the apparatus is used. Each boat has its own peculiarities, and a knowledge of these is just as helpful in

using submarine signal apparatus as in using the steering apparatus or in knowing how the vessel handles herself in a seaway.

When an observation for direction is made the receivers are taken from the hooks and the observer listens alternately on the port and starboard sides of the vessel by throwing the semaphore switch. A complete observation is made on the " A " set before changing to the " B " set, or *vice versa*, but the " set " switch is not thrown each time the semaphore switch is moved.

In using the apparatus the bell will be heard at a greater distance when the boat is running slow or stopped than when running fast; for then there is little or none of the water noise which is noticed when running at full speed.

Generally speaking the deeper the draft the better the results,

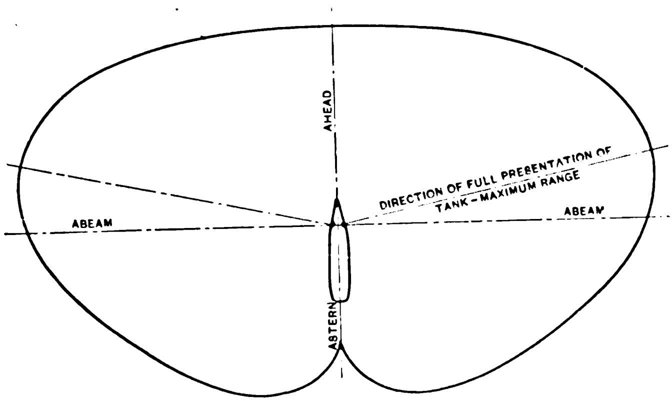


FIG. 7.—SKETCH ILLUSTRATING RELATIVE DISTANCES THE SUBMARINE BELL CAN BE HEARD AT DIFFERENT ANGLES.

for the surface water is not a good conductor of sound. Consequently with other conditions equal a boat loaded deep will get better results than when running light.

The results obtained in a calm sea will be better than those obtained in rough water. This is due to the pitching and rolling of the ship which make the water noises louder than in calm weather and cause the depth at which the receiving apparatus is submerged to vary greatly. This condition is unfavorable for the best results.

In testing to pick up the bell, the ship is swung to port or starboard. If the bell sound is louder when semaphore reads " Port " the bell is on the port side; if louder when the semaphore reads " Starboard " the bell is on the starboard side. To obtain

the exact bearing the ship is swung towards the bell until the sound is equal on both sides. The bell will then be dead ahead.

I have shown Fig. 7 to illustrate the following points: The bell can be heard at a greater distance when two or three points on either bow than when dead ahead.

It can be heard at the greatest distance when at right angles to the face of the tanks.

It can be heard a shorter distance when aft of the beam.

When dead astern it cannot be heard.

The reason for these results is as follows:

The bell sound can be heard best when that part of the ship on which the tanks are placed is most directly presented to the bell, namely, at right angles. It is apparent that when the bell is dead ahead the presentation of this portion is very slight, that it increases as the bell bears more nearly abeam and decreases as the bell passes aft of the beam.

When the bell is directly astern, that part of the ship's side on which the tanks are placed does not present itself to the bell and the path of the sound is broken up by the action of the propellers.

It will also be noted that the sound of the bell increases in volume and improves in quality of tone as it is approached, and that in passing it the sound will be loudest when the bell lies abeam and will decrease as the ship travels away.

These results are due to the fact that the bell sound is louder the nearer you are to the bell, and to the presentation of the tanks, as already described.

Inter-Ship Submarine Communication

Up to the present time inter-ship submarine signaling has not been adopted generally by commercial shipping. For navy work, both in this country and abroad, inter-ship signaling has been used most successfully.

In the case of submarine boats which must navigate under water the signal bells as well as the receiving apparatus are considered indispensable. The submarine boat tenders are also equipped with complete sending and receiving apparatus and we have records of trials where communication has been successfully carried on between submarine boats and their tenders at distances of from five to eight miles.

It is interesting to note that since inter-ship submarine signaling has been used in our navy we have not had a serious accident

to a submarine boat. On the other hand, in foreign navies during the past two years no less than five submarine boats have been lost, none of which were provided with this aid to navigation.

In the navigation of submarine boats the moment of greatest danger is when the boat has been totally submerged and is coming to the surface. This was the case in the loss of the French submersible *Pluviose*, which was struck as she came to the surface by the cross-Channel boat *Pas De Calais*. Had the *Pluviose* been provided with receiving apparatus her officers would have been warned of the approach of the *Pas De Calais* by the sound of her paddle wheels in time to avoid the accident.

With reference to the application of inter-ship submarine signaling to passenger or commercial ships I would say that at

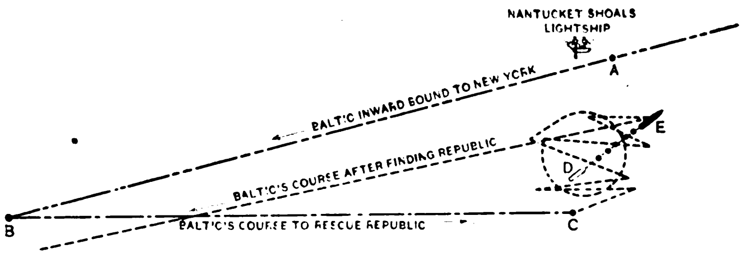


FIG. 8.—SKETCH DRAWN BY "BALTIC'S" OFFICER, SHOWING HOW "BALTIC" FOUND "REPUBLIC."

A.—" Baltic " inward bound to New York. Lays course by submarine bell on Nantucket Lightship.

B.—" Baltic " receives wireless from sinking " Republic " saying that she is within the range of the submarine bell on Nantucket Lightship. " Baltic " lays course by dead reckoning for " Republic.".

C.—" Baltic " comes into a range of submarine bell on Nantucket Lightship and starts search for " Republic."

E.—" Baltic" finds " Republic," the latter having drifted from *D* to *E*.

Cherbourg the tenders of the North German Lloyd equipped with submarine bells steam outside the harbor and act as guides for the liners coming in, thus saving much valuable time and avoiding the danger of a close and uncertain approach to the coast in fog.

Fig. 8 reproduces a sketch drawn by an officer of the *Baltic* showing how the *Republic* was found, to illustrate how necessary it is that every steamer should be fitted with a submarine bell as well as the submarine signal receiving apparatus. The *Baltic* coming from Europe had picked up the submarine bell on the Nantucket Shoals light-ship, laid her course from that point to New York and proceeded eighty miles when she got the wireless message that the *Republic* was in distress.

Captain Sealby, of the *Republic*, sent a wireless to the *Baltic* that he was in hearing of the submarine bell and gave his bearings on Nantucket Shoals light-ship as determined by the bell. On returning to the *Republic* one of the first things that the captain of the *Baltic* did was to get in range of the submarine bell on Nantucket Shoals and get the bearing given by Captain Sealby.

The *Baltic* then took up the search for the *Republic*, keeping within range of the submarine bell on Nantucket Shoals light-ship until the *Republic* was found. After taking on board the passengers of the *Republic* and the *Florida*, the *Baltic* proceeded to New York in a dense fog, making Fire Island and Ambrose Channel light-ships by the submarine bell. The captain of the *Baltic* afterwards reported that all three light-ships were made by use of the submarine bell long before he heard the light-vessel fog whistle.

Had the *Republic* been equipped with a submarine bell the *Baltic* would have been guided as directly to it as it was to the light-ships, and twelve hours' delay spent in searching for the *Republic* would have been avoided. In a serious accident an hour's delay, or even less, may mean the difference between the rescue of those in distress or a terrific loss of life.

In the case of the *Titanic* disaster, fortunately for those saved the sea was calm and the weather clear, and therefore there was little difficulty for the rescuing steamer to find the life-boats. The fact, however, remains that the necessity for haste in reaching them was great and that had the weather been thick the boats might have drifted and those on board perished before being found.

A small submarine hand bell rung from a lifeboat could be heard by any vessel equipped with receiving apparatus for miles and by means of it the drifting lifeboats or a steamer in distress could be located just as surely as the positions of light-vessels are now determined by the hundreds of steamers which have been equipped with apparatus to receive submarine signals.

Growth of Submarine Signal System

While a number of light-ships and shore stations were equipped with submarine signal bells prior to 1906, both in the United States, Canada, and abroad, these bells were put in on trial. These endurance trials were very successful.

On June 1, 1906, the Government began a two months'

test on five of the light-ships between Boston and New York to determine the efficiency of the submarine signal as an aid to navigation. The test was unusually severe; each light-ship was obliged to keep a submarine bell in operation continuously night and day throughout this period with an interval of not less than six seconds between blows. The test of sixty-one days of continuous ringing was equal to two and one-half years of service according to the highest number of hours that the fog whistle had been in operation on Ambrose Channel light-ship.

The result of the test was so successful that the Government immediately purchased submarine bell equipments for ten light-ships. Since that date it has extended the system to the light-vessels on the Atlantic and Pacific coasts and the Great Lakes.

There are at the present time a total number of 52 bells operating in United States waters. Canada also adopted the system and has increased the number of bells along her coast until to-day there are a total number of thirteen.

The French Government and the German Government equipped their light-vessels with submarine bells and later Trinity House, the English Lighthouse Board, adopted the system on November 1, 1906, after exhaustive tests.

The number of submarine signal stations has increased steadily from year to year and there is now hardly a country with any extent of coastline which does not furnish this aid to navigation.

In connection with this I might say that China has put in submarine signal stations within the past two years and that during the coming year the Panama Canal will be equipped with submarine signals.

Growth of Receiving Apparatus

As the number of signal stations were increased the number of vessels equipped with apparatus to receive these signals has also steadily increased; among them being the great transatlantic vessels belonging to the White Star, Cunard, North German Lloyd, Hamburg American and Allan lines. There is a total of about 900 vessels equipped with submarine signals at the present time.

The system of sending and receiving signals under water which five years ago was hardly more than a probability has now become a reality.

A paper presented at the 29th Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June 27, 1912.

THE WIRING OF LARGE BUILDINGS FOR TELEPHONE SERVICE

BY FREDERICK L. RHODES

In modern office buildings, hotels and apartment houses large numbers of telephones are required. It would be inconvenient and impracticable to run a pair of wires through one of these large buildings each time a telephone is installed, in order to establish connection with the outside wire plant of the telephone system, as is ordinarily done when telephones are installed in residences or small business buildings. To overcome this difficulty, when the plans are prepared for an office building, hotel or apartment house, a forecast should be made of the probable future requirements of the building as a whole for telephone service, and facilities provided for a certain amount of cabling with the necessary terminals and subsidiary wiring. All large cities contain many buildings that are cabled and wired for telephone service according to a comprehensive plan and, of the smaller places, there are few that do not have some buildings of a character requiring more or less provision of this kind.

Building Plans Should Include Provision for Telephone Wiring. Owing to the type of building construction generally employed, and the large number of telephones to be served, unless suitable facilities are provided in advance for accommodating the cables and wires, and for running them through the walls and floors, the work will either be unsightly in spite of all precautions to the contrary, or expensive and costly alterations will be required after the completion of the building to enable the wires to be effectively concealed.

It is therefore of prime importance to owners and architects that, in preparing plans and specifications for office buildings,

hotels or apartment houses, suitable arrangements should be made for such telephone wiring and terminal boxes as the character and use of the building will demand. As every large building to a certain extent presents problems of its own, advantageous and economical arrangements can frequently be suggested by those who are specially familiar with work of this kind. It is to the advantage of telephone companies as well as building owners to have adequate facilities provided for the cables and wires, and telephone companies are glad to place their experience freely at the disposal of those who are planning the erection of buildings that require special provisions to be made. It is now the general custom for architects to send for the telephone company's experts in these matters to give them such information as they need to plan this work in the best way.

Classification of Buildings. In the following pages are described the general methods that have proved satisfactory for wiring buildings for telephone service. From this standpoint buildings may be divided into two classes:

1. Office and loft buildings.
2. Hotels and apartment houses.

The conditions that make a broad distinction between the two classes are these: In office and loft buildings the telephones do not remain fixed either in number or location for any extended period, varying with the requirements of the individual tenants who will use more or less of the telephone service according to their respective kinds of business. In hotels and apartment houses the number of telephones is fairly definitely fixed, being almost invariably one for each room in a hotel and one or two for each apartment in an apartment house.

The office or loft building requires a permanent cable system supplemented by a multitude of branches consisting of pairs of wires whose function it is to connect the individual telephones or private branch exchange switchboards with the permanent cable system. This permanent backbone of cable extends upward from the basement, branching out and terminating at suitable distributing points on the several floors. These distributing points or cable terminals must be sufficiently numerous and so located that the changing requirements of the tenants can readily be met by running individual pairs of wires as needed to connect the telephones with these terminals.

It is, therefore, apparent that an office building must have a more comprehensive and flexible system of wiring than a hotel

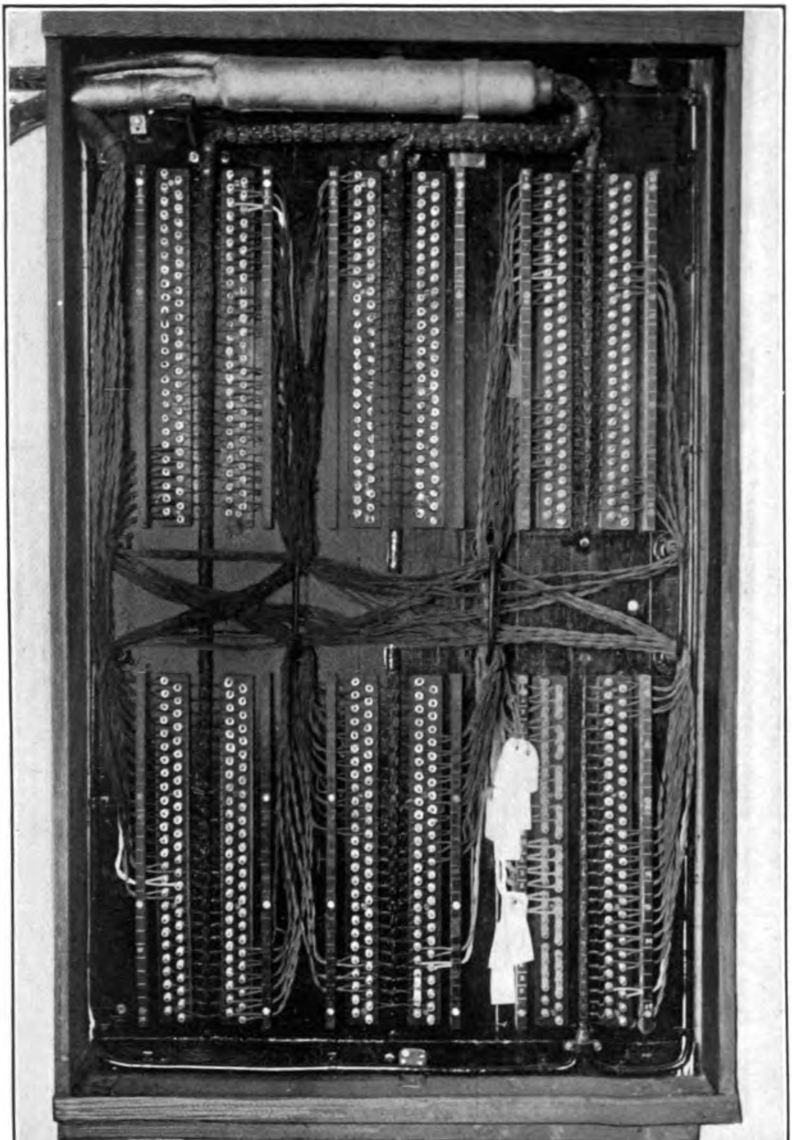


FIG. 1.—MAIN TERMINAL BOX, CAPACITY FOR TERMINATING 312 PAIRS OF WIRES. [RHODES]

The sliding door is removed to show the cross-connecting wires between pairs in the feeder cable and the house cable.

or apartment house on account of the different character of the telephone service required. In the office building only a portion of the wiring system is permanent. In a hotel or apartment house practically all of the wiring is permanent.

Office Buildings

General Scheme of Wiring. In large office buildings one or more cables from the nearest telephone central office are brought to some convenient point, usually in the basement of the building. At this point the house cable system begins. A main terminal box (Fig. 1) is furnished and placed by the telephone company at this point so that cross-connections can be made as required between pairs in the house cables and pairs in the central office cables.

These main terminal boxes in the case of large buildings are necessarily somewhat bulky and the question of the size of the box that will be needed in any particular case may well be taken up with the telephone company by the architect or builder in order that sufficient space for it can be provided in a convenient and appropriate location at the foot of the riser shaft or conduit as the case may be. A dry, clean and accessible place should be selected. In some sections of the country, where buildings are in localities subject to floods, it will be well to provide space above the basement so that the telephone service will not be interrupted due to water getting into the basement.

From the main terminal box one or more riser cables are run to the top of the building. The riser cables gradually diminish in size as they extend up through the building. From the riser cables, subsidiary or branch cables of proper size are taken to distributing centers on the several floors. The locations of these centers should be chosen so as to admit of the shortest practicable wire runs to the offices, without making objectionable work necessary to conceal the wires.

Each subsidiary cable ends in a subsidiary terminal box, the purpose of which is to enable connections to be made readily between the cable and the individual pairs of wires that are run to each telephone. These subsidiary terminal boxes when placed by the telephone company are fastened against the walls of corridors near the ceiling and constitute the ends of the permanent wire system. Not infrequently the owner of the building desires to own the subsidiary terminal boxes in order that he may provide recesses for these boxes and small doors to match the trim of

the building so that the boxes will be concealed from view. Where the boxes are built into the walls it is important that they should be of ample capacity on account of the trouble and expense that would result if they should prove inadequate and have to be replaced. It is customary to allow a greater margin for growth where the boxes are built in than where they are merely

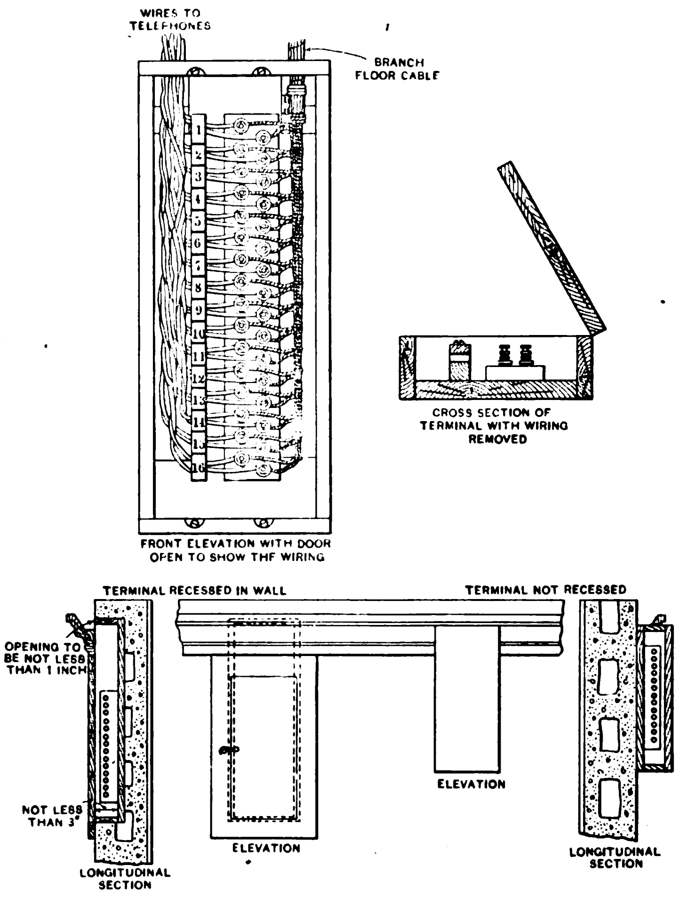


FIG. 2.—SUBSIDIARY TERMINAL BOX—15 PAIRS.

fastened against the wall. Where a conduit system has been installed on the various floors for the purpose of distributing wires to each office, the subsidiary terminals are located at the centers of the conduit system. Fig. 2 shows a subsidiary terminal box, recessed in a corridor wall, under the molding, and also a subsidiary box placed against the wall under the molding.

Forecasting the Number of Telephones. In forecasting the number of telephones that will probably be required in an office or loft building, the principal factors to be taken into account are the "renting floor area" of the building and the character of the business district in which it is situated, with special reference to its proximity to railway terminals, important streets and business centers.

Buildings in the financial district of a city ordinarily demand more telephones per unit of floor area than do buildings located in the commercial districts. In computing the "renting floor area," only the office floor space is considered; hallways, elevator shafts and light wells are omitted. In all cases a safe margin for growth must be allowed. The following table shows rough average figures for telephonic density in office and loft buildings, based on a large number of cases:

Kind of building	Character of district	Pairs of telephone wires per 1000 sq. ft. of renting area
Office	Financial	4 to 5
Office	Commercial	2½ to 3½
Loft	Commercial	1 to 2

Size of Riser Cables. By basing the size of the riser cables on the renting area and the expected telephonic density as influenced by the character of the locality (checking this by a study of the probable number of offices and the requirements of prospective tenants) the cable system for any office or loft building may be planned with reasonable assurance that provision will be made for the maximum service required. On account of the requirements for battery feed wires and ringing current for private branch exchanges, the riser cables necessarily contain more pairs than do the cables that run from the building to the telephone central office.

Shafts or Conduits for Riser Cables. In buildings over 12 stories in height or in buildings of less height, where large riser cables are required, it is preferable to place the riser cables in suitable shafts rather than in conduits, as the advantage of having the cable protected by conduits is offset by the difficulty of installing and properly fastening the large cables in the conduits and making large complicated splices in the junction boxes that are required with a conduit system.

If properly installed a conduit system is the best equipment for buildings less than 12 stories in height where small cables are to be placed, as the cables are effectually protected against injury. It is important, however, to remember that the success of a conduit system for installing vertical cables depends entirely on a perfect installation. The conduits must be of proper size and if possible free from bends. If bends are absolutely necessary, they should be made with a radius not less than three feet. The junction boxes at splicing points must be at least two feet square and the conduits must enter the boxes adjacent to a side in order that the cable may be bent and placed in a horizontal position for splicing.

Cable Shafts. Cable shafts should extend from the basement of the building to the top floor and should be easily accessible at each floor for the placing and splicing of the cables. Usually the shaft can best be located in a corridor partition, or in the wall of some public space leading out from the corridor, so that an opening can be made into the shaft from the corridor and covered with removable paneling or doors.

It is desirable to have a separate shaft for telephone cables and wires, as the placing of steam, water or gas pipes and light and power wires in the same shaft with the telephone cables renders the latter liable to injuries that may result in interrupting the telephone service.

Underground Cable Entrance to Building. Repairing basement walls and their waterproofing, due to the necessity for cutting through them, can be avoided if architects will specify a three-inch iron pipe sleeve for each ultimate underground cable entering the building, these sleeves extending through the wall at the point of entrance. The location of the point of entrance should be taken up with the telephone company in order that it may suitably fit in with the underground conduit system outside the building.

Junction Boxes. Riser cables ordinarily diminish in size as they go up the building. When a building is provided with conduits for both riser and subsidiary cables the conduit may diminish in size in the vertical section in the same relative manner as it is proposed to diminish the riser cable. Where a separate conduit is installed for each subsidiary cable a splice is required between the subsidiary and the main cable and a junction box is required wherever one of these splices must occur. These boxes should be approximately 24 inches square by five inches

deep (inside dimensions) in order to enable the splices to be properly made and stowed away. In a system of this kind the subsidiary cables and the sections of the riser cable between floors are run separately and spliced in the junction boxes.

Terminal Boxes. The terminal boxes in which the subsidiary cables end must be large enough to accommodate the necessary connecting blocks. In most cases, boxes 18 inches square by five inches deep (inside dimensions) are sufficiently large. These boxes are installed on each floor as near the wiring center as possible, and, where there is a conduit system on the floor, they are connected with each office by a 5/8 inch or 3/4-inch conduit which ends in the office at an outlet located either at the baseboard or the molding. Outlets should be located at the baseboard when it is of wood. If the baseboard is of metal or marble the outlet should be located at the molding.

In many cases owners of buildings do not desire to install conduits from the subsidiary boxes on each floor to every office. By providing suitable moldings, properly arranged to carry the individual pairs between the subsidiary boxes and the offices, wiring that is practically concealed can be done without the expense of conduits, and as the wiring is permanent only as far as the subsidiary boxes, the system is flexible enough to allow a suitable distribution of cable wires among the various rooms on a floor.

Where this plan of wiring is employed the subsidiary boxes may be made smaller than where individual conduits to the rooms are installed. The following table shows the outside dimensions of the present standard sizes of subsidiary boxes:

Number of pairs of wires terminated in box		Height of box in inches	Width of box in inches	Depth of box in inches
Regular	Extra			
10	1	12½	6½	2⅜
15	1	16	6½	2⅝
20	1	21	6¾	2⅞
30	2	16	12	2⅜
40	2	21	12½	2⅜

Fig. 2 shows a front elevation and section of one of these boxes. The equipment consists of a connecting block strip and a form or fanning strip. The connecting block is of insulating material and carries a pair of binding posts for each pair of cable wires to

be terminated in the box. The form strip is of wood and serves merely as a guide to preserve an orderly arrangement for the individual twisted pairs that run from the telephone to the box. These twisted pairs pass through holes in the form strip and are secured under the nuts and washers of the binding posts as are also the wires of the cable.

Cross-Connecting Boxes. Where a private branch exchange switchboard is to be installed, a cross-connecting box will be required. The wiring center in a case of this kind is at the cross-connecting box and not at the private branch exchange switchboard.

Use of Moldings. As shown in Fig. 2, the subsidiary boxes

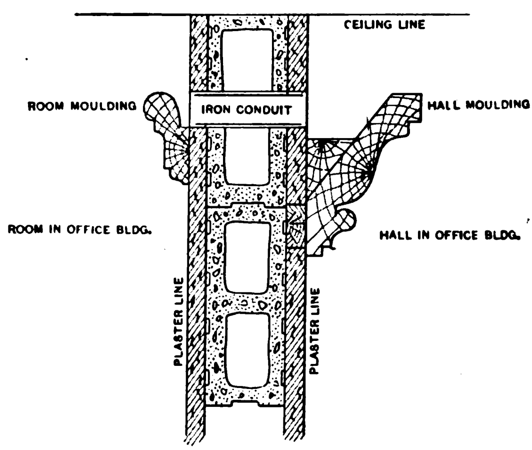


FIG. 3.—CROSS SECTION OF PARTITION SHOWING HALL MOLDING, ROOM MOLDING AND PARTITION CONDUIT.

are placed near the ceiling and wide shell molding, Fig. 3, should be provided in the halls for carrying the paired wires from the subsidiary boxes to the rooms. A smaller molding should also be provided in the individual rooms for carrying the wires to the particular locations desired. The space for the wires at the tops of these moldings should not be enclosed but should be left open. The object is to provide a continuous trough from each subsidiary box reaching out to every room that is to be fed from it. Fig. 3 illustrates a section of one of these moldings.

Where it is necessary to make a concealed run across the ceiling of a hall, in order to avoid carrying exposed wires across the finished ceiling or to obviate making a circuitous run around the

hall to reach rooms on the opposite side from the subsidiary box, conduit should be laid in the ceiling before the plastering is completed to enable a small cable to be carried across the hall to provide for such lines. (Fig. 4.)

Where the wires enter a room from a hall molding, a piece of 3/4-inch conduit should be placed in the partition to enable the wires to be carried through it from the molding in the hall to the molding in the room. This avoids the necessity for drilling holes through the partition after the building is completed, which would be likely to result in damaging the finished wall. The conduit should either be lined with insulating material or the sharp edges around the inside of the pipe should be rounded off. (Fig. 3.)

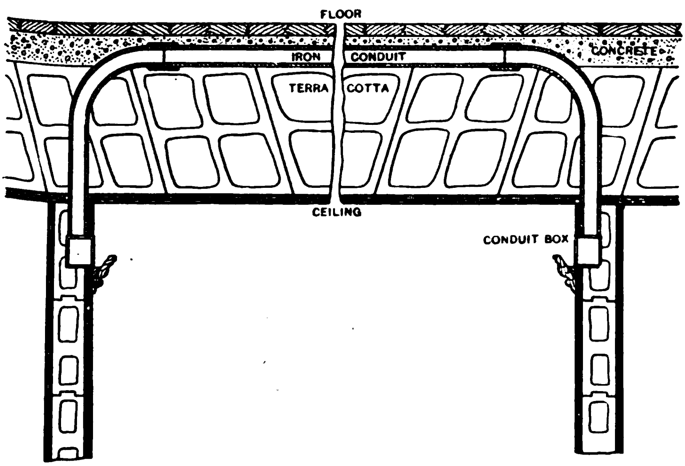


FIG. 4.—METHOD OF PLACING IRON CONDUIT ACROSS CEILING OF HALL.

Kind of Cable. Paper insulated lead covered cables, such as are used by telephone companies in their outside plant, are the most desirable for use in building work. These cables are smaller and less costly for the same number of wires than cables of rubber insulated wires. With this type of cable all of the terminals must be made with lead covered silk and cotton insulated cable, boiled out in beeswax or approved compound, and carefully shellaced, as the paper insulation will not stand handling if exposed, and moisture must be prevented from entering the paper insulated cable. Should the terminal of necessity be in a particularly damp location it must be made with rubber covered wires.

General Arrangement of Riser and Subsidiary Cables. From what has already been said it will be seen that the general arrangement of riser and subsidiary cables is practically the same irrespective of whether conduits or shafts and moldings are provided.

The splicing of the subsidiary cables for each floor to the riser cable is usually done so that a given pair of wires in the riser cable is available for use on more than one floor. This is termed "bridging" the conductors and furnishes a multiple system of distribution. By this means the flexibility of the system is increased and fewer spare pairs need be provided in the riser cable than would be required if there were no "multipling."

From records of a large number of house cable systems it has been found that by bridging about two-thirds of the pairs in the riser cable at the subsidiary branches the most advantageous balancing of facilities is obtained. If less bridging is done it often happens that many of the subsidiary cables become congested before the riser cable. Owing to the use of standard size cable it is frequently necessary to make either risers or subsidiaries somewhat larger than the exact number indicated by the density study. The use of such cables may cause the proportion of bridging to vary from one-half to three-quarters.

In splicing the subsidiary cables to the riser cable in buildings of moderate size, it is not economical to open the large riser cable on each floor. In such cases, the plan followed is to take out from the riser cable at one floor the small subsidiary cables for several floors and to carry them from that point up or down to their respective floors.

Methods of Installation. If the riser cable is placed in a shaft the main cable and its subsidiary branches are often spliced together on the roof of the building or in some upper story and then lowered into place. In some cases the splicing is done in the telephone company's shop and the cable shipped to the building ready to be installed.

For supporting the cable a steel strand is used. Two or three wraps of iron wire are made about the cable at frequent intervals and these are attached to the strand by separating the individual wires of the latter and passing the tie wires through the interstices of the strand. If the subsidiary cables are more than about 30 feet in length only a short section of each is spliced to the riser cable before lowering. In this case the subsidiary branches are run and spliced to these stubs after the riser is put in place.

Special Conduit Work. In the methods above described the facilities provide for locating the telephones on or near walls or partitions, as this is the most common location. It can sometimes be foreseen by owners or architects that telephones will be required at some distance from a wall or partition, as would be the case with a desk placed in the center of the room. Where an arrangement of this kind is desired the owner should provide a duct in the floor extending from the location of the telephone to the picture molding on the wall or to some other place easily accessible for wiring. A duct of this kind should end at the floor in a floor box covered with a flush plate.

It sometimes happens, particularly in buildings used by large corporations or firms, that entire undivided floors are occupied by large numbers of desks. Telephone service is frequently required at all, or a large part of these desks and the locations and arrangement of the desks on the floor may from time to time be changed. The floors of these buildings are often of fireproof construction. To meet a situation of this kind adequately it is necessary to be able to carry individual pairs of concealed wires to desks placed at any points on the floor, so that great difficulty and expense would be encountered in providing concealed wiring if suitable facilities admitting of the utmost flexibility were not provided in advance.

The best method of doing this is to carry branches from the riser cable in conduits to convenient building piers, placing subsidiary junction boxes at the bases of these piers. The entire floor is then provided with small floor outlets placed at the corners of squares about eight feet apart, each outlet being connected by conduit in the floor with the nearest subsidiary junction box at a building pier. Where the floors are not of fireproof construction, the individual pairs of wires are run in small channels grooved out of the floor beams on their upper surface. The locations of these channels should be accurately marked above the finished floors. Small brass nails are convenient for this purpose. When a telephone is required at a desk the flooring over the nearest channel is cut through, thus establishing a connection through the channel with a subsidiary terminal, conveniently placed, the wires being fished through the channel in the ordinary manner.

Arrangement of Conductors to Insure Flexibility in Operating the System. In order that the main terminal box may be as small as practicable the number of cross-connections to be made

in it should be kept at a minimum. This is also important from maintenance considerations. To enable this to be done the method of distribution is arranged in a similar manner to that employed in other portions of the telephone plant. A certain number of pairs of wires in the riser cable are directly connected to the cable entering the building from the telephone exchange. These connections are made in a lead covered splice and the pairs of wires thus spliced directly through do not appear in the main terminal box.

Certain other pairs in the riser cable are brought to terminals in the main terminal box. The remainder of the pairs in the riser cable are directly spliced to pairs in the exchange cable and these same pairs are also brought out by means of a branch splice to terminals in the main terminal box. If there are any extra pairs in the exchange cable that are not directly spliced to pairs in the riser cable they also are terminated in the main terminal box.

This arrangement, if the pairs have been skilfully distributed, permits of great flexibility and reduces to a minimum the number of cross-connections required in the main terminal box. The pairs that are connected straight through from the exchange cable to the riser cable without appearing in the main terminal box are used for the direct line telephones in the building and for private branch exchange trunk lines. The pairs of the exchange cable that appear in both the main terminal box and the riser may be used, first at the various floor boxes in the event of the congestion of the direct exchange pairs that appear in these boxes, and second in the main terminal box for battery and generator circuits and for overflow of business, due to erratic growth in lines on the various floors in the building, by cross-connecting to the house cable conductors extending to these floors. House cable pairs terminating in the main terminal box are used for private lines and miscellaneous circuits and for providing battery and generator circuits between the box and the various private branch exchanges by cross-connecting to the exchange cable in the main box.

Examples of Office Building Wiring

The Hudson Terminal Buildings in New York City, extending from Cortlandt to Fulton Streets, one block west from Broadway, afford an example of the facilities required for telephone service in the case of office buildings of the largest size. The two Terminal buildings are treated as a unit so far as the telephone wiring

FIG. 5.—PERSPECTIVE VIEW OF TERMINAL BUILDINGS, NEW YORK CITY. [RHODES]

is concerned. Together they contain nearly a million square feet of renting area and at the present time have about 3,000 telephones. These data, with Fig. 5, a perspective view of the buildings, will indicate the magnitude of the wiring problem.

The cabling and wiring of these buildings is illustrated by the following figures:

Fig. 6 is an elevation of the riser cables, showing the connections with the exchange cables and the general arrangement of the branch cables to each floor. Fig. 7 is a detail elevation showing typical "multipling" of the branches from the risers to the floors and of the subsidiary cables on the floor. Fig. 8 is a typical floor plan showing the locations of the riser cables, the floor cables, the floor terminals and the wire runs in the hall moldings to each office.

At the present time there are three 606-pair underground cables extending from the telephone central office to these buildings. The central office cables are spliced to the house cables near the main terminal. About 16 per cent of the pairs in the central office cables are connected directly to pairs in the riser cables that do not terminate at the main frame terminal of the buildings. The remaining 84 per cent of the pairs in the central office cables are bridged to pairs in the riser cables which also appear at the main frame terminal. All pairs from the central office cables that are directly connected to house cable pairs are marked *D F*. All pairs from the central office cables that are connected to house cable pairs that also appear at the main frame terminal are marked *F*. The balance of the pairs in the house cables (marked *H*) have no connection with pairs in the central office cables except by cross-connection at the main building terminal, where they may be connected as desired to pairs in the central office cables that are also bridged to riser cable pairs.

As new cables to the central office are added to meet the demand for additional telephone service in these buildings, the existing central office cable requiring relief will be left directly connected to the riser cable system and the bridged pairs will be transferred to the new cable.

The riser cables, of which there are five in all, are located in cable shafts beside the elevator shafts, Fig. 8. On each normal floor are provided conduits extending from the cable shaft to each of the five subsidiary terminals on that floor. In Fig. 8 these conduits and the subsidiary terminals are shown by solid lines. Broken lines represent the runs of individual twisted

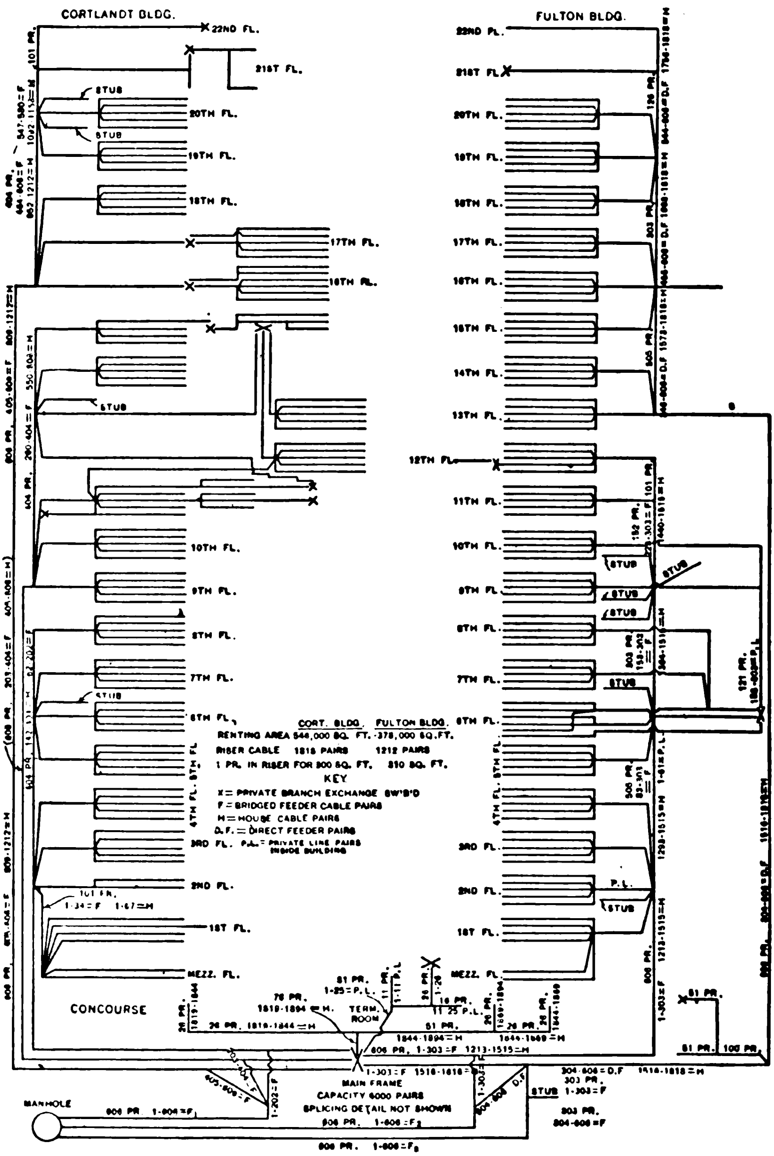


Fig. 6.—Terminal Buildings, House Cable Distribution.

pairs of wires in moldings from the subsidiary floor terminals to each office on the floor.

On account of its complexity, the entire scheme of multiple

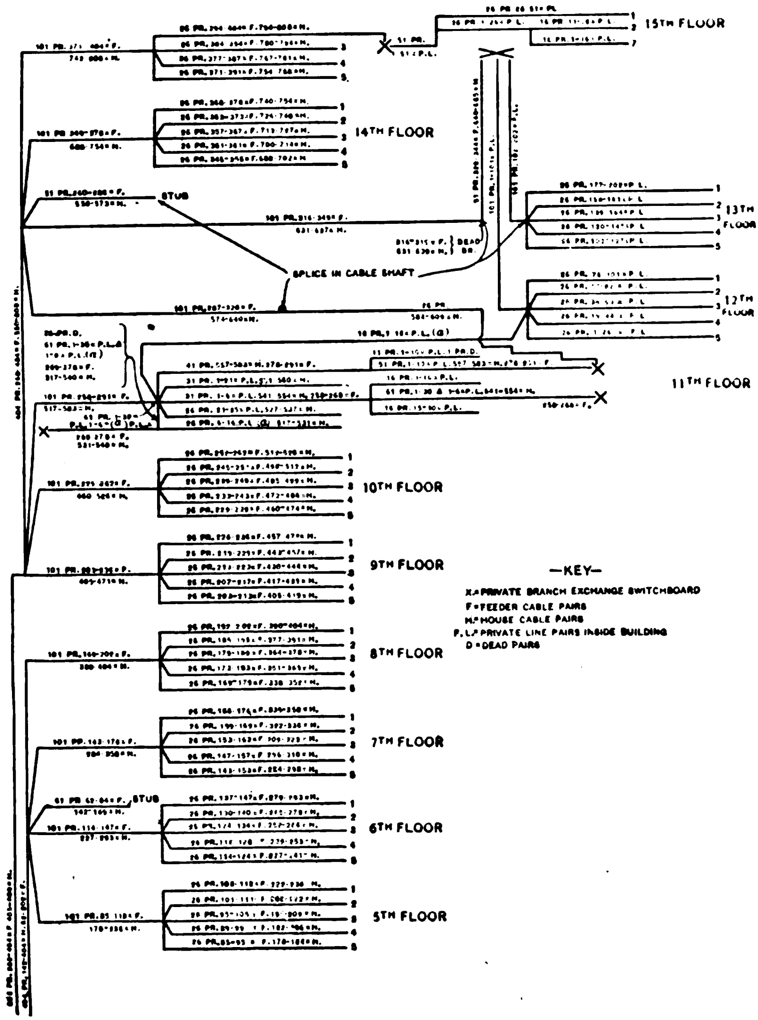


FIG. 7.—HUDSON TERMINAL BUILDINGS.
Detailed distribution of cable pairs on the 5th to 15th floors, inclusive, in Cortlandt St. Building.

distribution for these buildings is not shown in full detail. The principles are, however, illustrated in Fig. 7 which shows the complete lay-out of the distributing cables branching from two

points of the riser cable system of the southernmost (Cortlandt) building and feeding from the fifth to the fifteenth floors, inclusive. The distribution for the fifth to eighth floors inclusive represents one of the simplest cases in these buildings. That for the ninth to fifteenth floors is one of the most complicated due to the special demands brought about by certain private branch exchange requirements.

In portions of these buildings, on account of private branch

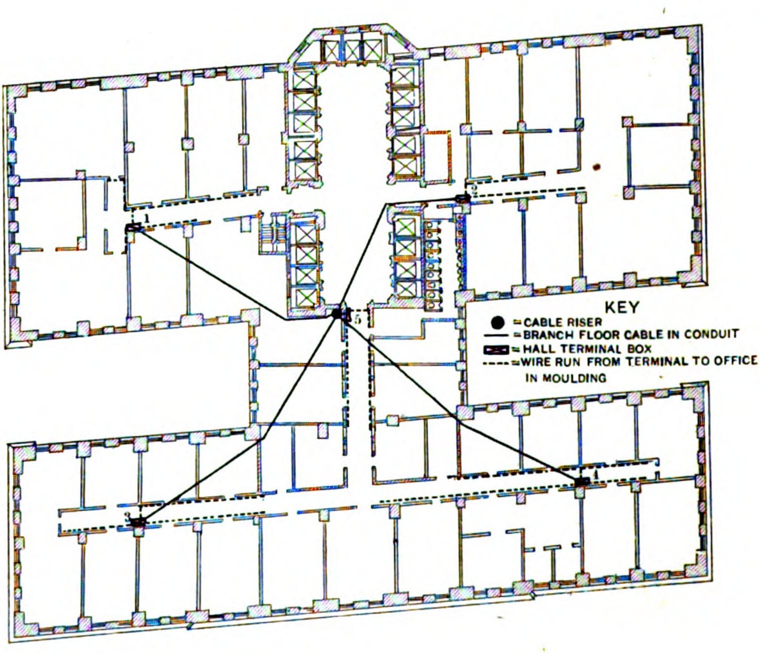


FIG. 8.—TERMINAL BUILDINGS—TYPICAL FLOOR PLAN IN CORTLANDT BUILDING.

exchanges, some of the floor distributing branches from the riser cables that would be needed to supply individual tenants, are not required at the present time. Stubs containing the cable pairs that would normally appear on these floors are, however, provided and left in the cable shaft so that, merely by splicing subsidiary cables to these stubs, service on these floors of a different character could readily be established if changed office conditions should render this necessary.

The requirements for telephone service in these buildings are

so large that a main distributing frame is installed to act as the main building terminal. This frame serves the same purpose as the terminal box equipment shown in Fig. 1, namely to enable the pairs from the central office cables to end in a compact series of terminal lugs, and the pairs from the house cables in another series of terminal lugs; the lugs being so arranged that, by short lengths of twisted pair wire, cross connection can readily be made between any pair brought to the frame from the central office cables, and any pair brought from the house cables. This permits great flexibility of distribution. In the "multipling" diagrams, Figs. 6 and 7, the numbering of the pairs in the house cable system is on the basis of two groups. All feeder pairs in the house cable system, whether directly spliced to pairs in the central office cables and not appearing at the main terminal or bridged to pairs in the central office cables and also appearing at the main terminal, are numbered from one up and designated either *DF* for direct feeder or *F* for bridged feeder pairs.

All pairs in the house cable system that terminate at the main terminal without being directly connected or bridged to the central office cables are numbered as a separate group from one up and are designated *H* for house pairs.

Eleven Story Store and Office Building. This building is chosen as an example of a complete conduit installation. Fig. 9 is a plan of one of the office floors and Fig. 10 shows elevations of the conduit system and the cable system. The diameters of the conduits are indicated in order to show how the conduits decrease in size with the cables as they rise up through the building.

Owing to the lower portion of this building being arranged for stores, the office distribution on certain of the riser cables does not begin until the sixth floor is reached.

Loft Buildings

Conduits for wires or cables are rarely provided in loft buildings. The riser cables are placed in shafts and the wires are distributed on each floor along the baseboards. The wire center on each floor is usually at the baseboard near the passenger elevator shaft. Although this arrangement is undesirable in many cases, it is difficult, on account of the floors being undivided and the locations of the telephones not being known until the premises are occupied, to make any provision in advance for distributing the wires. A system of conduits and floor boxes would be expensive and is not considered necessary.

Where one firm occupies the entire loft building, the size of the riser cable is determined entirely by the equipment of the private branch exchange switchboard and the probable future requirements of the firm as to telephone service. In a case of this kind the center of the wire system is at a cross-connecting box located close to the private branch exchange switchboard.

A modification of the method of distribution already described for office buildings is usually employed in loft buildings. The riser cable is divided into two parts termed "bridged feeder"

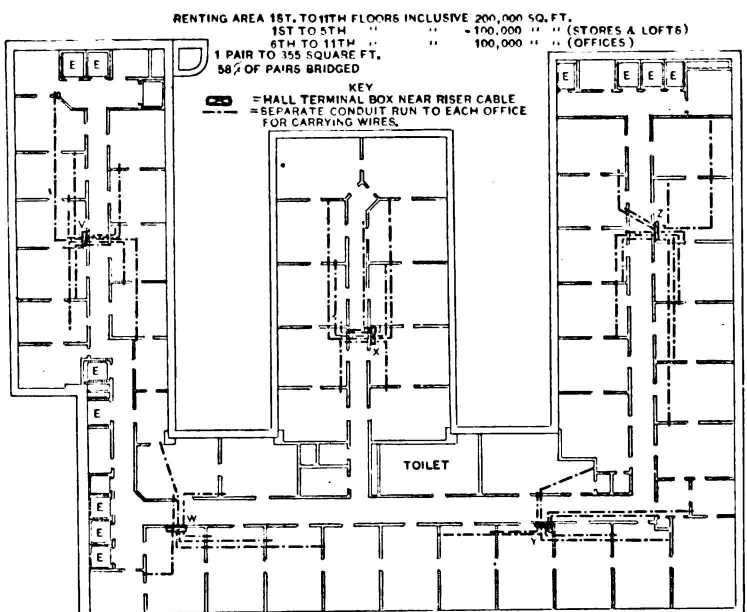


Fig. 9.—11-Story Office Building, Typical Floor Plan.

and "house cable." The house cable pairs are terminated in the main terminal box near the foot of the riser, and the bridged feeder pairs are directly connected to pairs in the exchange cable and also by a branch splice are terminated in the main terminal box.

Example of Loft Building Wiring. Fig. 11 shows the floor plan and cable distribution of a twelve story loft building. It will be noted that the arrangement of pairs does not agree with the statement that in loft buildings the riser cable is divided only into bridged feeder and house cable groups. This

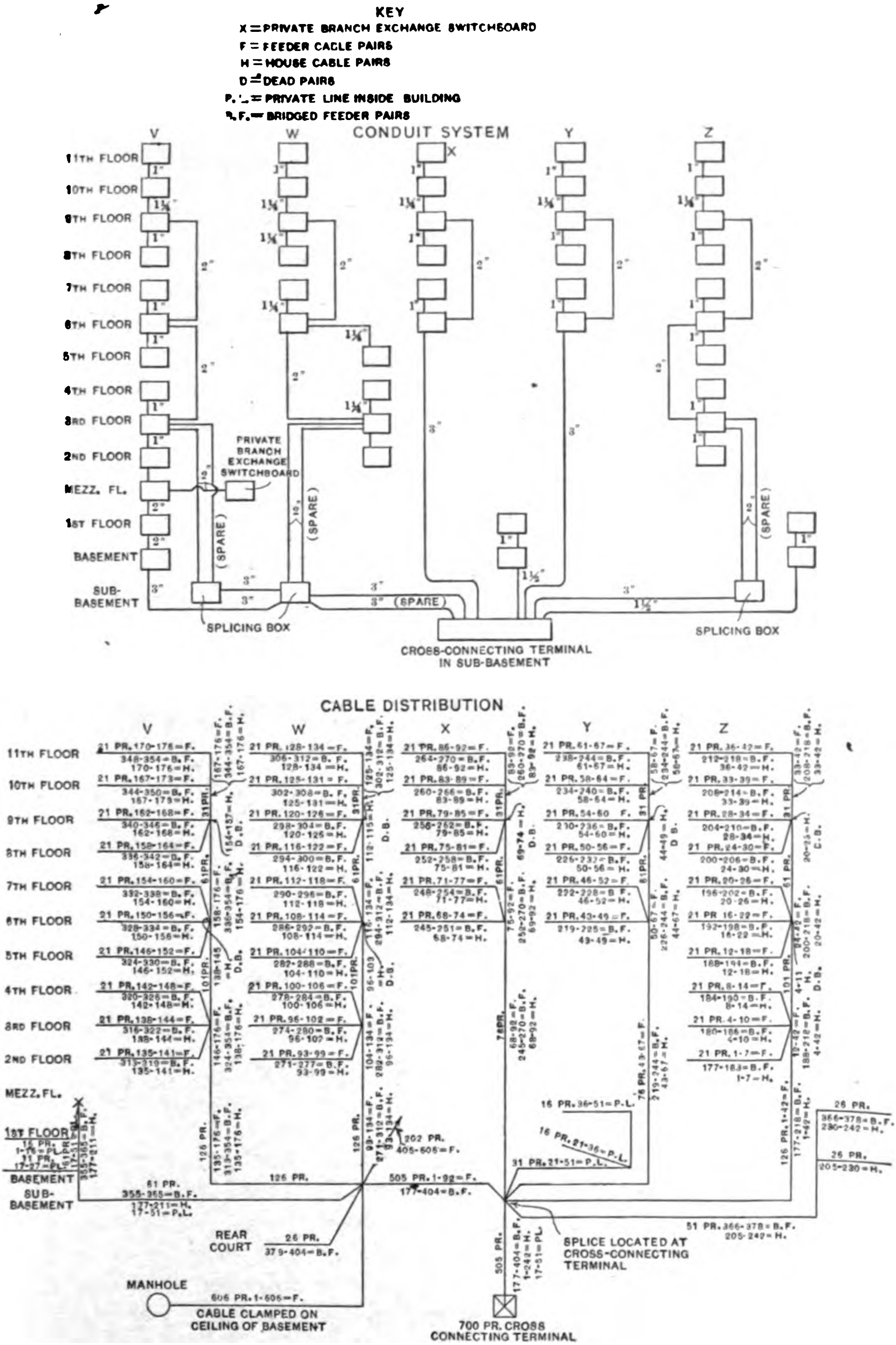


Fig. 10.—11-Story Office Building, Conduit System and Cable Distribution.

diagram shows, in addition to these groups, certain direct feeder pairs. The reason is that it is expected that this particular loft building will sooner or later be partitioned off for office use, and this condition has been anticipated in planning the cable distribution.

Hotels and Apartment Buildings

General Scheme of Wiring. The telephone systems for hotels and apartment buildings differ from those for office and loft buildings in one important respect. Hotels and apartment buildings can be wired in advance on a permanent basis on account of the probability that there will be no essential change in the number of wires needed, the ultimate requirements being

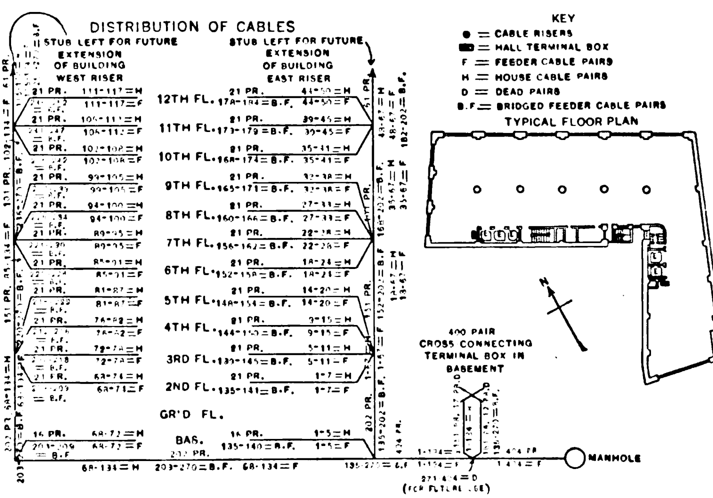


FIG. 11.—12-STORY LOFT BUILDING.

closely determined by the number of rooms or apartments. The locations for the telephones in the various apartments or rooms are also generally permanent and the relative locations of the telephones are the same on each floor.

The telephone system installed in these buildings consists of a private branch exchange switchboard located at some convenient point, usually on the ground floor. In hotels this private branch exchange switchboard is placed in or near the office. Telephones are installed in each room or apartment and wired to this switchboard. The latter is connected by the necessary number of trunk lines with the nearest central office of the telephone company.

The wiring problem is simple in comparison with that in office buildings. It consists of running a pair of wires from the telephone location in each room or apartment to a common center in the cross-connecting box near the private branch exchange switchboard. It is important to make provision so that the telephone company can run its wires from the cross-connecting box of the private branch exchange switchboard to some point in the basement where connection can be made to the central office cable. The latter cable is generally not run in conduit but is clamped to the ceiling of the basement.

Subsidiary Conduit. Conduits for distributing wires on floors in hotels or apartment buildings should not ordinarily be over 50 feet in length nor should they have more than three bends with a minimum radius of five inches. Any conduit 100 feet in length should not be less than one inch in diameter: 5/8-inch conduit should be provided for a maximum of two pairs of wires and 3/4-inch conduit should be provided for a maximum of four pairs of wires. For more than four pairs of wires it is preferable to run cable.

Hotels. In laying out the wiring system for hotels, in addition to one pair of wires for each room, as mentioned above, provision has ordinarily to be made for a small percentage of spares to provide for defective pairs and for a few direct lines.

From the wire center at the cross-connecting box near the private branch exchange switchboard a cable is extended through the basement or sub-basement to the foot of the riser shaft. The riser cable extends up this shaft as a diminishing cable with subsidiary terminals located at convenient points on each floor for reaching the various rooms. The wires are distributed on the floors either by molding or through conduits, as the case may be. In many of the modern hotel buildings complete conduit systems are provided for concealing the telephone wires and cables. In such cases the vertical conduits are installed at some central point and junction boxes are provided on each floor for splicing and terminating cables. From the junction boxes separate 5/8 inch conduits are extended to each room. The outlets in the rooms should be located four feet 10 inches above the finished floor for wall sets, this having been found by wide experience to be the most satisfactory height at which to place the telephone. For desk stands the outlets should be at the baseboard near the proposed location of the telephone. Where the floor area and the number of rooms are large it is often economical to have more than one terminal box on a floor.

Examples of Hotel Wiring

18-*Story Hotel*. Fig. 12 shows the floor plan of this hotel with the locations of the riser cables and the individual telephones in each room. The separate conduit runs from the riser terminals to the rooms are not shown in order to avoid confusion on the drawing. Fig. 13 shows elevations of the riser cables with the branches at each floor.

In this installation the riser cables (five in number) are placed in shafts and the wire distribution on each floor is in separate conduits to each room. It will be noted that no feeder pairs are provided in the riser cables.

17-*Story Hotel*. This is a complete conduit installation.

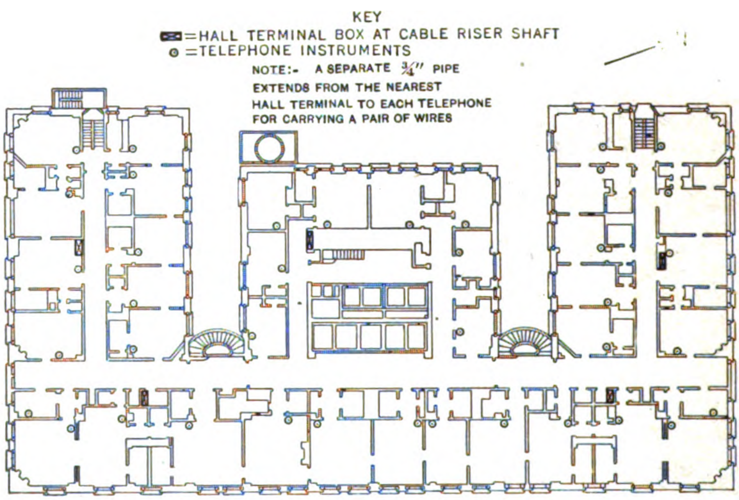


Fig. 12.—18-Story Hotel, Typical Floor Plan.

Fig. 14 shows the riser cable terminal boxes and individual telephone locations on a typical floor. Fig. 15 gives the elevation of the house cable system. This hotel has an apartment section which is cared for by the North riser cable. This section of the house has its separate switchboard. The other two riser cables feed the hotel portion of the house.

Elevator Apartments

Elevator apartment buildings are generally wired on the basis of two telephones to an apartment, one connecting to the private branch exchange switchboard and the other when desired, directly to the central office of the telephone company.

In most of the high class elevator apartment buildings it is the practise of owners and architects to provide conduits for concealing the telephone wires and cables. In some cases a vertical shaft is provided instead of vertical conduit.

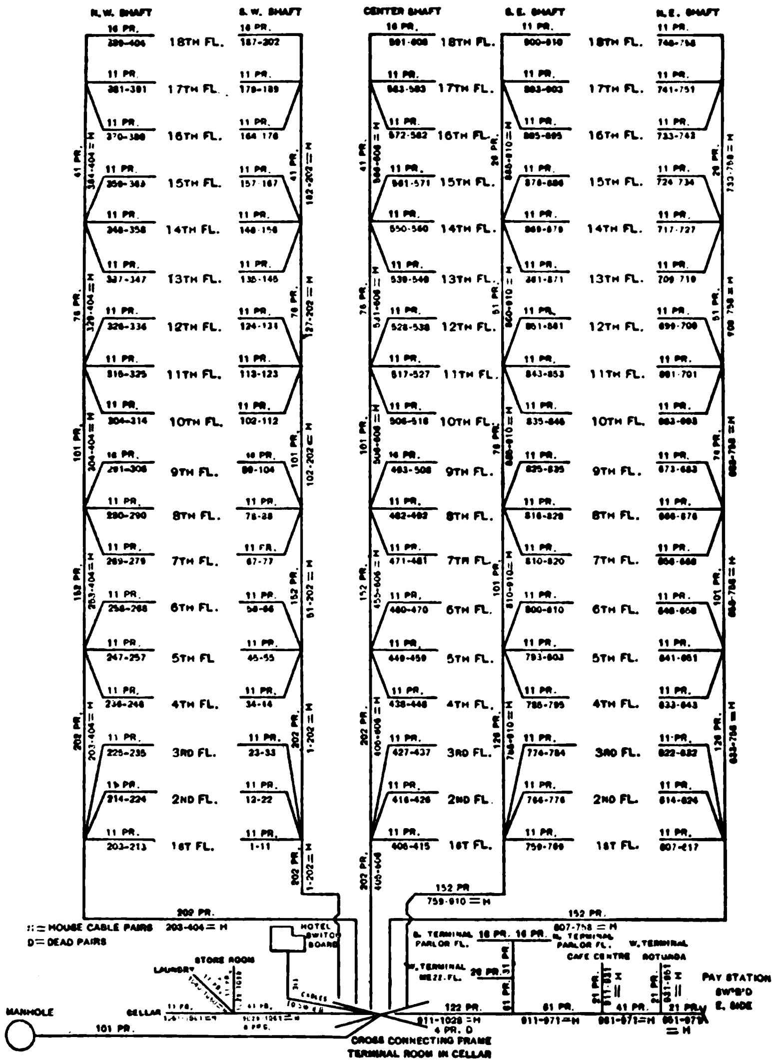


FIG. 13.—18-STORY HOTEL, HOUSE CABLE DISTRIBUTION.

Where the floor space occupied by each apartment is small and the horizontal runs on each floor are short a riser or diminishing house cable is placed. This cable is extended up through

the building in a conduit or a shaft, as the case may be, and branches containing a sufficient number of wires to provide two pairs for each apartment are terminated in junction boxes located at central points on each of the floors. From each junction box 5/8-inch or 3/4-inch conduits are extended to the location of the telephone in each apartment, the outlets being located, as in hotels, at the baseboards for desk telephones, and in the wall, four feet 10 inches above the finished floor, for wall telephones. This arrangement provides a flexible system, as the wires between the apartments and the subsidiary branches may be drawn in whenever service is required. As the horizontal run of conduit

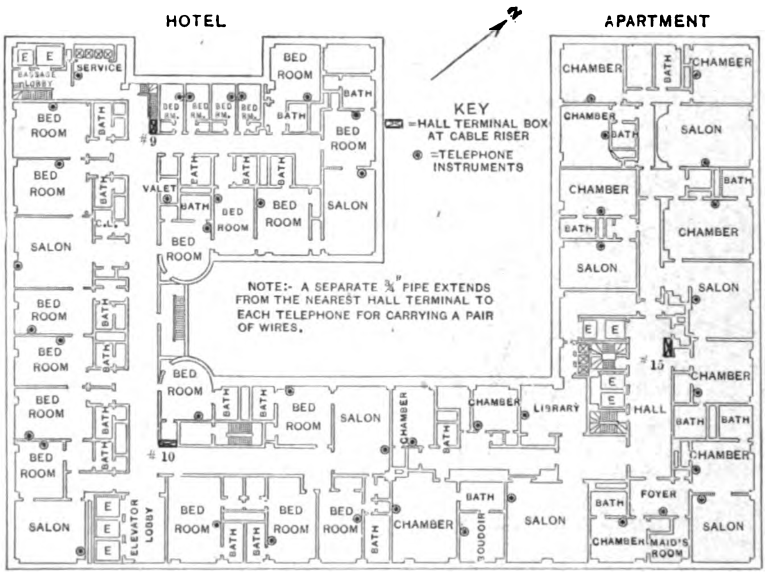


FIG. 14.—17-STORY COMBINATION HOTEL AND APARTMENT BUILDING, TYPICAL FLOOR PLAN.

on each floor is comparatively short, the cost of the conduit installation is minimized. There is a further opportunity for economy in installing conduits from the junction box to the apartments, as it is frequently possible to use a single run of conduit for two apartments instead of a separate conduit to each.

In apartment buildings where the floor space occupied by each apartment is large, the above arrangement would necessitate long runs of small size conduit on each floor. In such cases, to avoid the excessive cost of this conduit, the wires are usually distributed to the apartments by a vertical system of conduits extending from the basement up through each tier of apartments.

These vertical conduits diminish in size as they approach the upper portion of the building and the outlets in the apartments are located in the walls at the points where the telephones are to be placed.

In the basement, cables are extended from the cross-connecting box near the private branch exchange switchboard along walls and ceilings to the foot of each line of vertical conduits. At

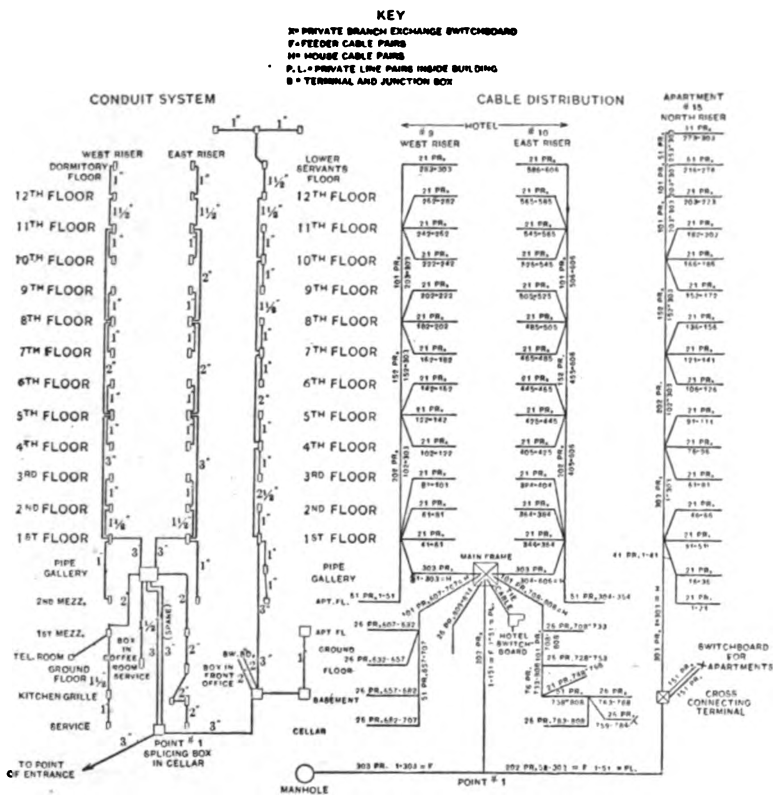


FIG. 15.—17-STORY COMBINATION HOTEL AND APARTMENT BUILDING, CONDUIT SYSTEM AND CABLE DISTRIBUTION.

these points terminals are established with sufficient conductors to provide two pairs of wires for each apartment to be cared for by the riser. The pairs of wires between these terminals and the apartments are pulled into the conduits as the service is required.

The size of the vertical conduit varies with the number of apartments to be served. Generally a conduit two inches in diameter in the basement diminishing gradually to 3/4 of an

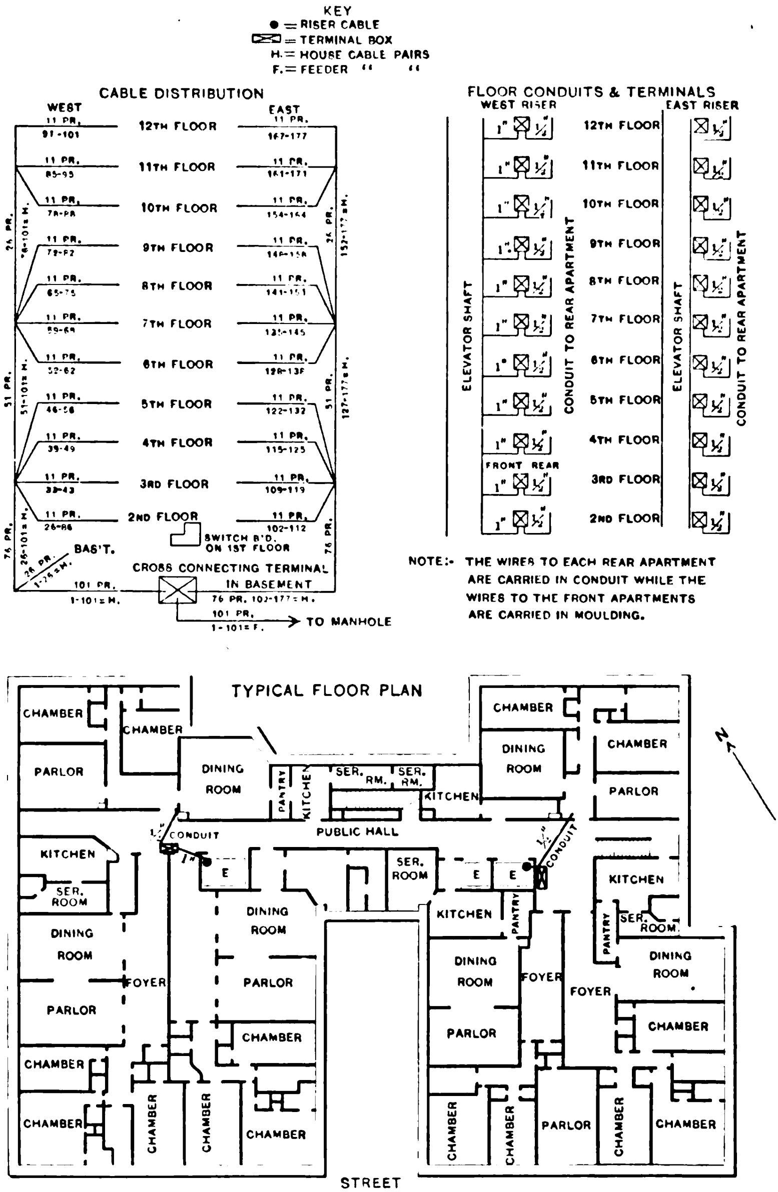


FIG. 16.—12-STORY ELEVATOR APARTMENT HOUSE.

inch at the upper floor is sufficient to care for buildings 10 to 12 stories in height, and a conduit 1¼ inches in diameter in the basement diminishing to 3/4 of an inch at the top for buildings from six to 10 stories high.

The number of vertical lines of conduit depends on the number

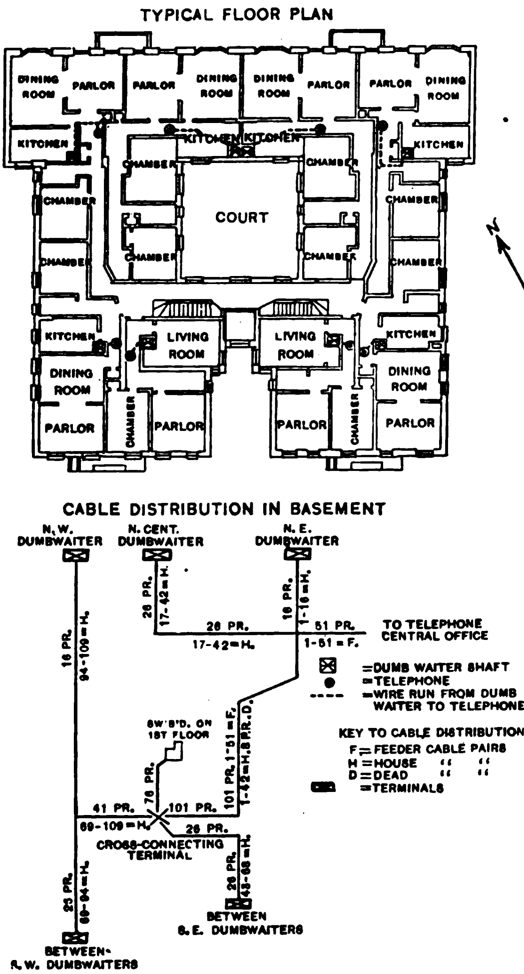


Fig. 17.—6-Story Non-Elevator Apartment House.

of apartments on each floor. Usually a separate line of conduits is required for each tier of apartments, but it is often possible to care for two adjacent apartments on each floor by a single line of conduit when the telephones in both apartments are to be placed on the dividing wall between them. This arrange-

ment is, however, open to the objection that installers must gain access to one apartment for the purpose of installing the telephone in another. In spite of this objection, from the standpoint of the owner this method is probably the best for buildings of this class as it minimizes the cost of installation of conduits and is flexible enough to admit of direct lines being installed when such service is required.

Example of Elevator Apartment Building Wiring. Fig. 16 shows a 12-story elevator apartment building with six apartments to a floor and stores on the front of the first floor. The two riser cables are run in the elevator shafts.

A diagram is given showing the junction boxes on each floor and the sizes of the conduits used for distributing the wires on each floor.

Non-Elevator Apartments

Apartment buildings of the non-elevator class do not as a rule exceed five or six stories in height and frequently have as many as 10 apartments on each floor. Buildings of this class are wired by extending lead covered cables from the cross-connecting box near the private branch exchange switchboard through the basement to the foot of each dumb-waiter shaft where terminals are established. The terminals are made large enough to provide approximately for a direct line and an extension telephone for each apartment cared for by the dumb-waiter shaft, when it is thought that direct service will be required. The allowance made for direct line service depends upon the neighborhood. The wires to the various apartments are extended up through the dumb-waiter shafts from the terminals in the basement as service is required.

In some cases these buildings are wired in advance by forming the wires into a cable and taping the cable to protect it against mechanical injury, one or two pairs being brought out at each apartment.

Example of Non-Elevator Apartment Building Wiring. Fig. 17 illustrates the case of a six-story apartment building having eight apartments to a floor. The wiring diagram shows the cable distribution in the basement to terminals at the foot of the dumb-waiter shafts.

The author wishes to acknowledge the valuable assistance of Mr. E. S. Worden and Mr. W. A. Taylor in preparing the illustrative examples of this paper.

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ELECTRIC DRIVE FOR PAPER MACHINES

BY J. S. HENDERSON, JR.

The satisfactory solution of any electrical problem is the result of a careful study of the conditions to be met and the application of the best apparatus available that will meet, or most nearly meet the specified conditions. Every paper machine has slightly different dimensions or requirements and a special investigation is necessary for each before the best type and characteristics of drive can be determined upon.

But regardless of the fact that each machine has its own peculiarities, the general operating characteristics are sufficiently similar so that they may be treated as a class in this paper. The Fourdrinier machine is probably adaptable to the manufacture of the widest range of weights and grades of paper and, being in much greater use than the cylinder machine, will be considered exclusively.

Although complex in structure, the principle of operation of a paper machine is quite simple and consists essentially of the separation of the paper fiber from its suspension in water, first by wire gauze, then by pressing and drying. The principal parts of the paper machine are: the wire, which is driven by the couch roll, the press rolls, the dryers, the calenders, the reel and winder. These constitute that portion known as the variable speed part of the machine while the various stuff pumps, vacuum pumps, screens, shake, etc., are driven at constant speed and constitute the constant speed portion of a machine.

Operating Characteristics of Paper Machines

A certain range in speed is necessary on the variable speed part of a paper machine in order to manufacture various weights

and grades of paper and even if only one weight and grade be made, a small speed range is desirable to take care of varying conditions and obtain maximum production at all times. The speed range required may be as small as 25 per cent or as great as 10 to 1, depending upon the class of output. Theoretically, the tonnage output should be constant at all speeds, but manufacturing conditions usually modify this so that the maximum production is obtained at some intermediate speed. The limiting features may be either in the forming, drying or handling of the paper. Considering the theoretical condition of constant production at all speeds, the thickness and weight would then vary inversely as the speed of the machine for a constant width of paper. From a paper-making point of view there are three characteristics for a successful drive, viz.

1. Entire speed range by simple and positive control.
2. Good speed regulation at any speed.
3. Uniform angular velocity at any speed.

Speed regulation is important, since variation in speed means variation in weight, but the regulation need not be considered from no-load to full load. Variation in load may be caused by throwing off or on the winder or other sections of the machine, but it is easily seen that if the dryers or any part before them is shut down, paper is not being produced and consequently it matters little what the speed variation is. In view of this fact it is customary to take the regulation between certain load points, as explained later.

It is also necessary to know how the load or the torque varies over the entire speed range in order to satisfactorily design a motor for this purpose. The greater part of the load of a paper machine is bearing, gear and belt friction, and when running without paper the torque required would be expected to be approximately constant, and the horse power varying in proportion to the speed. The effect of paper in the machine is to materially alter the speed-torque curve.

As previously mentioned, the thickness of the paper may be considered as inversely proportional to the speed, and it may also be assumed that the finished product always contains the same percentage of moisture. Then for a constant tonnage the same amount of water must be extracted at all speeds either by the presses or on the dryers. The drying surface is constant and the temperature cannot be materially increased without injuring the paper, but since the thicker paper is on the dryers a propor-

tionately longer time than thin paper, it might appear that the same amount of water could be evaporated. A study of this proposition shows that drying takes place differently in a thin sheet and in a thick one. In the thin sheet considerable water is evaporated through the sheet while in contact with the dryer, the remainder passing off between the dryers, while with a thick sheet practically all of the water is evaporated by heating alternate sides of the sheet and then exposing to the air between the cylinders. The conductivity of the surface of the thick sheet gradually decreases as it becomes drier, making it more difficult for the moisture to escape, so it becomes very evident that if the production is to be maintained more water must be removed before the paper reaches the dryers.

More water may be removed on the couch by increasing the vacuum and on the presses by increasing the pressure. A higher vacuum on a flat suction box adds very materially to the torque required to draw the wire over it, and additional weights on the press rolls also increase the torque required to drive them. Heavy paper also requires more torque on the dry end of a machine, both in the calendar and on the reel. Summing up the speed-torque curve of a paper machine, we find first, a nearly constant torque portion consisting of friction and second, a portion whose torque increases with decrease in speed, but not in the same ratio.

Types of Drive

Probably the first drives on paper machines were water wheels or constant speed engines connected to the variable speed shaft through some of the well-known types of variable speed cones. These can be built to give any desired speed range but are quite expensive and consume considerable power. To eliminate this intermediate transmission variable speed engines have been designed either for coupling or belting to the line shaft. Speed control is usually obtained by throttling and variable cut-off but even under these conditions it is difficult to obtain good regulation over a wide speed range and especially difficult to obtain uniform angular velocity. A flywheel designed for full speed has only 1/36 as much effect at 1/6 speed, so twin-cylinder or even four cylinder engines with various arrangements of cylinders are now being used to overcome this difficulty.

One of the first types of motor drive consisted of a constant speed induction motor replacing the constant speed engine, but using the same form of variable speed transmission. This drive

was the outcome of a desire to centralize the generating equipment in one plant, thus eliminating the maintenance and attendance of several small engines. The improved speed regulation and angular velocity were also of importance although about the same amount of power was consumed. Fig. 1 shows the variable speed cone drive. This motor may be started and stopped from any convenient place in the machine room, but all speed control is obtained from the cones.

It has been found that for machines which manufacture one product only, as for instance, "news," that only a small speed range is necessary and that this may be obtained satisfactorily on wound rotor induction motors. After a new machine and its crew are well broken in, it is generally possible to adjust the driving pulley so that practically all operation is at the highest motor speed. The poor speed regulation and uneconomical operation of the wound rotor motor when operating upon resistance, make it unsatisfactory for wide speed ranges and the use of a direct-current motor becomes necessary.

Since practically all paper mills avail themselves of the advantages of the induction motor for the general mill drives, a special direct-current supply for the machine is necessary. This generator may be driven by some form of prime mover, either engine or turbine, or a motor-generator set with either a synchronous or an induction motor may be used. There are many advantages in the use of a motor-generator set and especially with a synchronous motor. The following are some of the more important advantages:

1. Speed independent of load and depending upon frequency of supply circuit only.

2. Extreme simplicity and small amount of attendance and maintenance required.

3. Small floor space required, and may be placed in any desirable position, generally near the paper machine motor to save wiring and voltage drop.

4. May be run at high power factor or used for power factor correction.

Induction motors for this service have very small slip and good power factor but are affected by the voltage of the circuit as well as the frequency and cannot be used to improve the power factor.

With a direct-current motor there are two methods of varying speed; one by varying the field current, and the other by varying

the impressed armature voltage. The first method permits of carrying approximately constant horse power at all speeds while the second method gives approximately constant torque, or the horse power is in proportion to the speed. It has been previously shown that a paper machine requires neither constant horse power nor constant torque, so it is necessary to investigate these two forms of control in order to see which is best adapted and also what modifications may be made to obtain the most satisfactory equipment.

Control by Shunt Field Only. The cost of manufacture and speed regulation limit the speed range that can be obtained by this method, but an economical limit is about 4 to 1, although motors with a 6 to 1 range have been built. The maximum current occurs at maximum speed and weakest field, so that the poorest speed regulation will be obtained when working upon the lightest paper. The motor must be designed to take care of the maximum conditions and consequently at all lower speeds is working below its capacity. For instance, consider a machine requiring 150 h.p. at the maximum speed and 50 h.p. at $\frac{1}{4}$ speed. The operating conditions might then be as follows:

Horse power	Rev. per min.	Lb. torque	Volts	Amperes
150	800	985	230	535
50	200	1310	230	200

From this it is seen that although the motor is designed to carry 535 amperes only 200 amperes are required at the low speed. Many plants have several machines installed and it might appear that one direct-current supply source with motors having shunt field control would be most economical and cheapest, but it has been shown that this is often not the case, and that a separate generator for each machine is often advisable to prevent any possible influence on one machine from the other machines. There is no doubt that a motor of the above characteristics will successfully drive a paper machine within certain speed limits, but there is a greater initial investment for this speed range than is necessary.

Control by Armature Voltage Only. As an example of the voltage control, assume a machine which requires 150 h.p. at maximum speed, which requires a 7 to 1 range and twice the torque at the low speed as at the high speed. With voltage control a separate generator is required for each motor, although if de-

sired, two generators could be driven by one synchronous motor. The operating conditions of the motor at its limiting speeds are as follows:

Horse power	Rev. per min.	Lb. torque	Volts		Arm. Amperes
			Arm.	Field	
150	800	985	230	230	535
43	114	1970	35	230	1070

It is seen from this table that at the low speed the voltage of the generator and the motor are so low that it is impossible to conceive of good regulation, especially in view of the large current at that speed. Although only 535 amperes are required at the high speed which corresponds to 150 h. p., the armature of both the motor and the generator must be designed for 1070 amperes which is required at the minimum speed. This means that the armatures of both machines really have a capacity of about 300 h.p. Another disadvantage of this form of control is that the current increases as the speed decreases, thus tending to cause excessive heating in the motor, since the ventilation is greatly reduced at the lower speeds.

Control by Field and Armature Voltage. Since the characteristics desired for the paper machine are not met by either of the above forms of control, but since each has some of the desired characteristics, it seems reasonable to expect that some combination of the two might be made which would exactly meet the requirements of any machine. As an example, take the last mentioned machine which required 150 h. p. at maximum speed with a 7 to 1 speed range. The entire range may be obtained by using various percentages of field and armature control, but for an example it might be assumed that the amperes at a maximum and minimum speed were to be equal and this would then give a definite speed of the motor for normal voltage and full field. Fig. 2 shows a theoretical performance of such a motor operating a machine in which the torque required at the minimum speed is twice that at maximum speed, and it has been assumed that the increase in torque is proportional to the decrease in speed. From these assumptions the horse power and ampere curves have been calculated, based on a 230-volt supply circuit and reasonable motor efficiencies. It is seen that in order to have the same current at maximum and minimum speeds, it is necessary to use a motor having a normal full field speed of

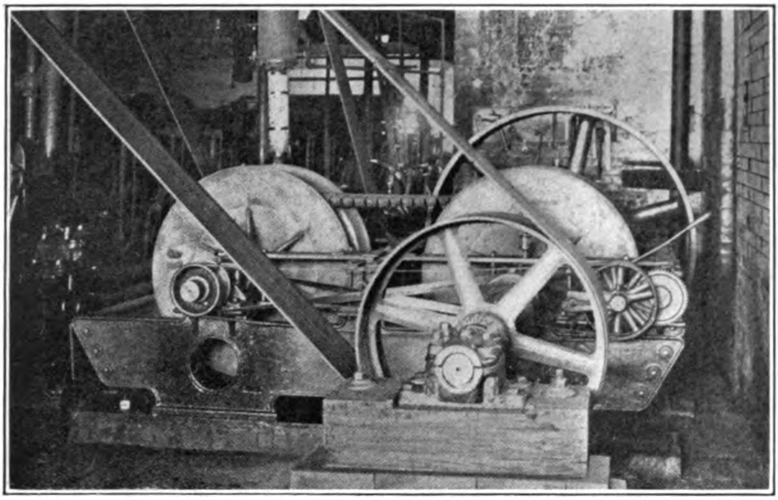
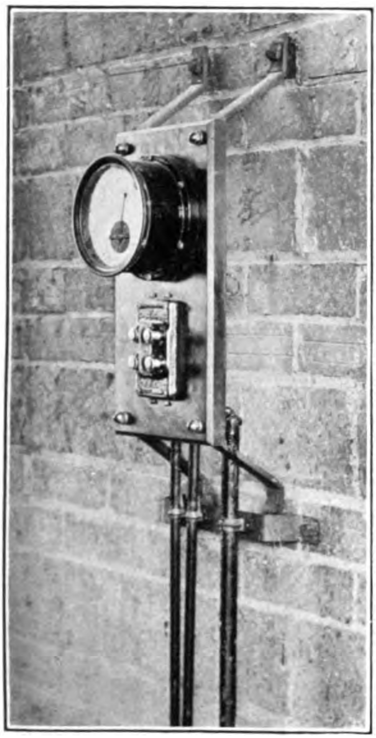
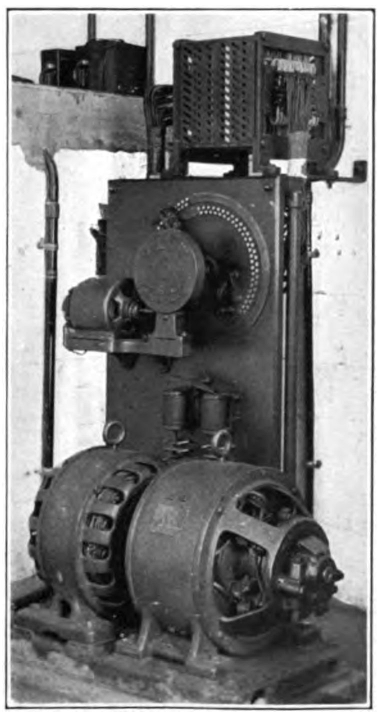


FIG. 1.—VARIABLE SPEED CONE DRIVE. [HENDERSON]



[HENDERSON]

FIG. 3.—PUSH BUTTON STATION AND SPEED INDICATOR (FEET PER MIN.) IN PAPER MACHINE ROOM.



[HENDERSON]

FIG. 4.—MOTOR OPERATED COMBINATION FIELD RHEOSTAT FOR SPEED CONTROL, AND EXCITER SET FOR MOTOR-GENERATOR SET AND PAPER MACHINE MOTOR.

340 rev. per min., using field control above and voltage control below this point. This gives a ratio by the field control of 2.35 to 1 and a voltage ratio of 3 to 1, both of which are within good commercial limits and tend towards the use of standard equipment. A standard generator will operate at full load and one-third voltage satisfactorily, and a motor designed for the given speed range can be adjusted in connection with the generator to give good regulation at voltages below normal.

Paper Machine Control. The control for a paper machine should be as simple, substantial and "fool proof" as possible since continuity of service is of utmost importance. The start-

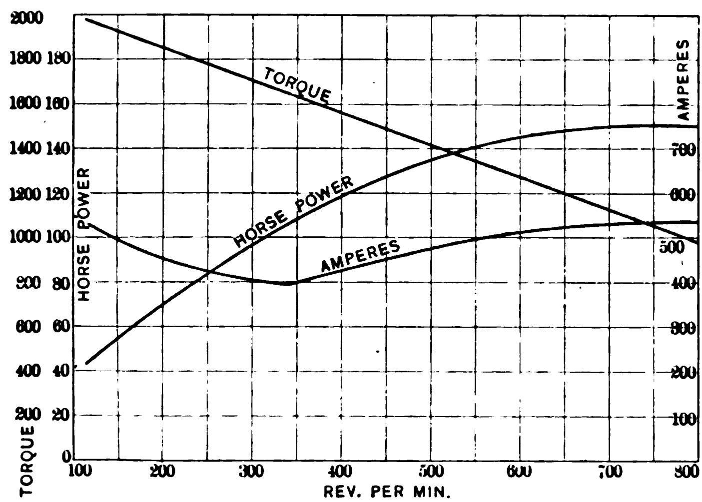


FIG. 2.—LOAD CURVE OF 150-H.P. MOTOR.
114-340 rev. per min. by voltage control.
340-800 rev. per min. by field control.

ing and stopping of large direct-current motors is now accomplished almost universally by automatic control, and push buttons for the control of circuit may be placed at any convenient point in the paper machine room. The speed control for the system last outlined consists of a rheostat in the field of the generator and of the motor, although to simplify operating conditions they are usually combined in one rheostat. If desired, a motor-operated rheostat may be used, in which case the control in the paper machine room consists of four push buttons only marked Start, Stop, Fast and Slow. It has been found that 100 operating points cover practically all manufacturing conditions,

although rheostats having more points have been built. The resistance should be so adjusted as to give the same percentage speed increment for each notch instead of equal increments. With a machine having a range from 100 to 400 ft. per minute and 100 points each step would correspond to about $1\frac{1}{3}$ per cent increase or about 16 in. for the first step and 5.5 ft. for the last step. The regulation of the motor is not as close as the percentage variation per step and it is an acknowledged fact that the weight of paper due to the supply of stock may vary several per cent. Consequently more than 100 points of control are unnecessary since a variation in load or in stock will correspond to several points of control.

Fig. 3 shows all the control that is in the paper machine room when a motor-operated rheostat is used. Above the four push buttons is a speed indicator reading in feet of paper per minute. This meter is operated from a magneto driven from the variable speed shaft and shows immediately what change in speed is obtained when operating the push buttons.

In Fig. 4 is shown the motor-operated rheostat which gives the 100 points control, and in front of this panel is seen the exciter set which excites the fields of the synchronous motor, the direct-current generator and the direct-current motor. The synchronous motor-generator set is at the right of this set.

Summary

A successful paper machine drive should give the desired speed range in a simple and positive manner, should have good speed regulation at each speed from about $\frac{3}{4}$ to full load, and should be able to carry all loads economically and satisfactorily. It is hoped that the above discussion shows that for most cases these conditions can be best met by using the combination control as last outlined.

The writer wishes to thank Messrs. B. G. Lamme, C. W. Drake, C. E. Wilson, and William Caine for constructive criticism.

A paper presented at the 29th Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June 24-28, 1912.

THE RUNAWAY SPEED OF WATERWHEELS AND ITS EFFECT ON CONNECTED ROTARY MACHINERY

BY DANIEL W. MEAD

In the selection of hydroelectric units, the operating speed of the turbines should be so chosen as to give the most efficient results under the varying conditions of operation. When the head of water is constant, the choice, unless modified somewhat by the necessary synchronous speed of the generator, should ordinarily be the speed at which the turbine will operate with the highest efficiency with the normal condition of load.

Under operating conditions the normal speed of the turbine is usually maintained, as the load varies, by the action of the turbine governor which opens or closes the gate or gates by which the water is supplied to the turbines, as the load on the connected generator, and consequently, on the water wheel, increases or decreases. If the changes in load take place without a corresponding change in the quantity of water admitted to the wheels, the speed will necessarily vary, increasing as the load decreases, and decreasing with an increase in load. Under the condition of maximum load, with the turbine gate at or near maximum opening, a sudden dropping off of the load without a corresponding change in gate opening will give rise to a considerable increase in speed, which has in some cases resulted in disaster to the connected generators, when such generators had not been designed for the overspeed to which they were subjected. Such accidents have usually been due to the breaking or sticking of the governor or its connections, whereby the control normally exerted by the governor on the gate opening has been accidentally discontinued, allowing the turbine, as the load dropped, to

speed up and run away. Such conditions, while not common, may happen in any hydraulic turbine installation, and to assure safety under such runaway conditions the generator or other rotary machinery connected with the turbine must be so designed that it will operate with safety at such runaway speed as is likely to occur.

At present it is current practise to design the generators for a possible 100 per cent overspeed in order to assure safety under such conditions. Such a basis for design often involves a large extra expense in generator construction, on account of the necessary extra strength of the rotor, and an inquiry as to the safe allowance for overspeed which should be made under varying conditions of operation and installation should, therefore, be of interest and importance in securing the necessary safety of the installation, combined with maximum economy in construction consistent with such safety.

NOMENCLATURE

The following symbols will be used in the discussion that follows

D D_a = diameter of homologous wheels or wheels of same type.

E = energy.

e = subscript e attached to any coefficient shows that the value of the coefficient as expressed is for the conditions of maximum efficiency of the wheel.

F = force.

g = acceleration of gravity 32.16.

h h_a = head under which wheels are to operate.

h_1 = head of one foot.

l = length of brake arm or leverage of resistance.

n n_a = rev. per min. of wheels of diameter D and D_a under same head; also rev. per min. of wheel of same diameter under heads of h and h_a.

n_1 = rev. per min. under one-foot head.

P P_a = power of wheels of diameter D and D_a under same head; also the power of the wheel of same diameter under head h and h_a.

P_1 = power of wheel under one-foot head.

S = space passed through.

v = velocity of water due to head.

v_a = average velocity.

v' = velocity of circumference or periphery of impeller which may be measured on any fixed diameter.
v_r = resultant velocity.
W = weight or resistance applied.
w = unit weight of water (per cubic foot).
π = 3.14159 = ratio of circumference to diameter of the circle.
ϕ = v'/v = ratio of periphery velocity of turbine to spouting velocity of water.
ϕ_e = ratio of wheel velocity under conditions of maximum efficiency.
ϕ_{max} = ratio of wheel velocity at runaway speed.
$\triangle$ = coefficient of speed = speed of one-inch wheel under one-foot head.
$\mathcal{P}$ = coefficient of power = power of one-inch wheel under one-foot head.
N_u = the speed of a wheel at one-foot head of size sufficient to develop one horse power.
$\mathcal{P}_s$ = power-speed coefficient = the square of the unity speed.

Some Elementary Principles of Turbine Governing

The writer has already pointed out in another place* that the power delivered by any waterwheel may be expressed in terms of resistance overcome by the wheel in a known distance and in a known time by the formula

$$P = \frac{2\,\pi\,l\,W}{33000} \times n$$

In this formula, P = power,

$\frac{2\,\pi\,l\,W}{33000}$ = resistance overcome per revolution, and

n = the number of revolutions per minute.

The actual variations of resistance and speed under certain conditions are shown in the upper curve of Fig. 1, and the resulting variations in power under various speeds are shown by the lower curve of the same figure. The conditions illustrated in Fig. 1 are not applicable to normal operating conditions of a

*See "Water Power Engineering" p. 440.

hydroelectric installation, which require constant speed, but the conditions illustrated do apply to the accidental conditions above outlined and to the actual working conditions of a pump driven by an hydraulic turbine, where the pressure in the delivery pipes from the pump is allowed to vary somewhat. The upper curve line *A X B* illustrates the actual and varying relations of resistance to speed in a turbine operating at a fixed gate opening. The point *A* shows the condition under which the resistance is so great that the turbine is held stationary with the

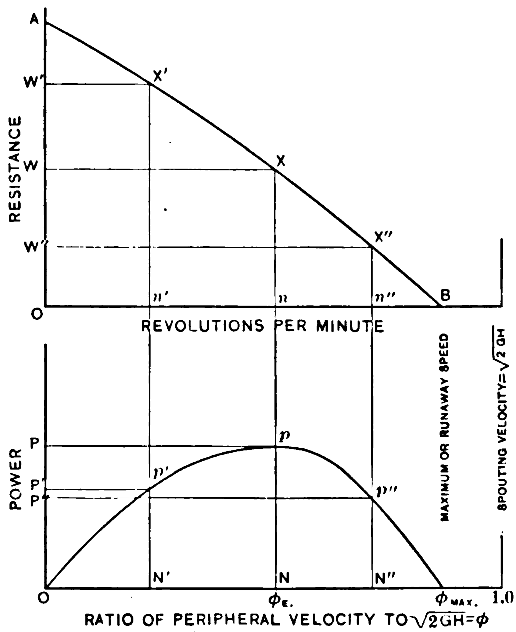


FIG. 1.

result of no power output (see lower curve). The point *X* shows the condition where the relation of resistance to speed is such as to result in a maximum power output of the turbine under the gate conditions considered. The point *B* shows the conditions under which the exterior resistance is completely removed and the entire energy of the water, as far as utilized at all, is expended in overcoming the wheel friction, resulting in maximum speed and zero power output.

A turbine driven pumping plant with variable pressure in the discharge pipe system will give self-regulation as indicated in

Fig. 1. In such case the point A represents a pressure in the system so great as to result in the stopping of the pump, and hence no speed and no pump discharges. Point X represents moderate pressure and normal discharge for which the system is designed, while point B represents the entire removal of pressure and the pump discharging its maximum under the gate condition. In practise, the actual variation extends to a limited extent only on each side of point X and a radical change in discharge of pressure under satisfactory working conditions must be accompanied by a change in the gate opening.

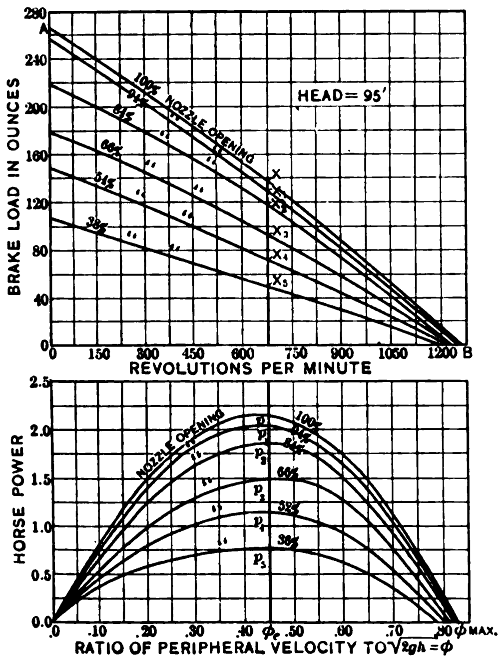


FIG. 2.

Fig. 2 constructed from experimental data* illustrates the results which must obtain for the satisfactory regulation of a constant speed hydraulic unit, and consequently, of a hydroelectric unit. Here again the upper curves show the actual relations of resistance to speed at various gate openings, while the lower curves show the relations of power to speed at the same

* See Figs. 15 and 16, Bulletin 337, University of Wisconsin. "The Relation of Experimental Results to the Theory of the Tangential Wheel."

gate openings shown by the upper curves. In the lower curves the speed factor is expressed as a ratio ϕ between the peripheral velocity of the wheel and the spouting velocity of water. Under such conditions satisfactory operation will be represented by the line $X X_1 p p_1 \phi_e$. The point X and the corresponding point p (on the line of 100 per cent nozzle opening of both upper and lower curves) represent the conditions of maximum gate opening, and consequently of maximum power. If the wheel is improperly selected for the load to be carried, and the power demands exceed this limit, a slowing down in speed will result as illustrated in the discussion of Fig. 1, and under such conditions the service will be satisfactory. If, however, the power varies only between the maximum and zero, satisfactory regulation must be accomplished by a proper change in the nozzle opening as the load varies, the point of operation dropping from position p to p_1, p_2, p_3, etc., as the power demands decrease, or rising from p_5 to the higher position as the power demands increase. This result is accomplished in practise by a turbine governor, the details of the operation of which are immaterial for this discussion. Now, if at any point of the load the governor becomes disconnected and the load suddenly varies, the gates may either remain fixed or swing to a fixed position, and a variation in speed will result similar to that illustrated in Fig. 1, or by any one of the upper curves of Fig. 2, which corresponds to the fixed gate opening. If the load is entirely removed a runaway speed will result which may vary according to the fixed gate condition under which this accident occurs.

Fig. 2 illustrates the experimental results from a 12-in. tangential wheel under a 95-foot head, operating under a load applied by a prony break. It will be noted that the operating condition is taken at 675 revolutions per minute, or with $\phi_e = 45$, (that is, with the periphery of the wheel moving with a velocity 45 per cent of the spouting velocity of the water under a 95-foot head).

In this case, at the maximum or runaway speed ϕ did not exceed $\phi_{max.} = 80$ for 36 per cent gate opening, or $\phi_{max.} = 84$ for 100 per cent gate opening, and if a generator had been connected to this wheel these speeds would have been slightly reduced by the amount of power necessary to operate the unloaded generator. In this case it is evident that the runaway speed of the wheel would be 186.5 per cent of the normal speed at full gate and 177.5 per cent of the normal speed at 36 per

cent gate, without considering other than the actual wheel friction.

The Hydraulics of Runaway Speed

In order to present this subject clearly, it is necessary to consider, briefly at least, the hydraulics of the turbine as it affects this problem. A jet of water spouting from the nozzle of a wheel will acquire a velocity v due to the head h represented in the formula

$$v = \sqrt{2\,g\,h} \tag{1}$$

and will possess energy in foot-pounds per second E due to velocity v and weight of water discharged per second, $W = qw$, as follows

$$E = \frac{W\,v^2}{2\,g} = \frac{q\,w\,v^2}{2\,g} \tag{2}$$

The energy of the jet leaving the orifice is the product of a force F which acting on the weight of water $q\,w$ for one second gives it the velocity v.

The space passed through by the force in one second in raising the velocity from 0 to v is

$$S = v_a\,t = \frac{v}{2} \tag{3}$$

and therefore the work is

$$F\,S = \frac{F\,v}{2} \tag{4}$$

which is also an expression for the energy of the jet. Therefore, we may write

$$\frac{F\,v}{2} = \frac{q\,w\,v^2}{2g} \tag{5}$$

and therefore

$$F = \frac{q\,w\,v}{g} \tag{6}$$

The force F will be exerted against any obstruction in its path and its magnitude will depend on the momentum of the moving stream of water and is directly proportional to its velocity. It is also a function of the angle through which the jet is deflected.

If friction be ignored the stream will be diverted without change in velocity and the force exerted in the original direction of the jet will be equal to the momentum of the original stream less the component, in the original direction, of the momentum of the diverted jet. (See Fig. 3.)

$$F = \frac{q\,w\,v}{g} - \frac{q\,w\,v}{g}\cos\alpha = \frac{q\,w\,v}{g}(1 - \cos\alpha) \qquad (7)$$

If the jet is deflected 180 deg. by means of a semi-cylindrical bucket, cos 180 deg. = − 1, and therefore (see Fig. 4)

$$F = 2\,\frac{q\,w\,v}{g} \qquad (8)$$

Tangential wheels utilize the impulsive force of a jet impinging against buckets attached to their circumference and practically semi-circular in section.

The bucket must move under the impulse in order to transform the energy of the impact, and the ratio of v', the velocity of the center of the buckets, to the velocity, v, of the jet, is indicated by ϕ.

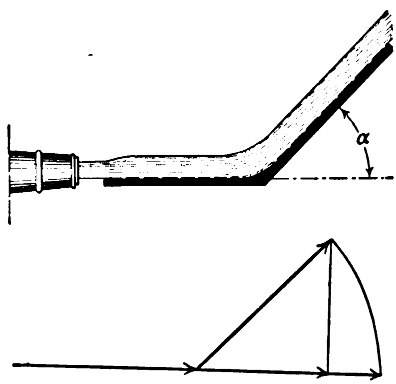


FIG. 3.—FORCE OF DIVERGING JET.

$$\phi = \frac{v'}{v} \qquad (9)$$

The force F exerted on the moving bucket is dependent on the relative velocity, v_r, of the bucket and jet

$$v_r = v - \phi\,v = (1 - \phi)\,v \qquad (10)$$

The relative weight of water that strikes a single bucket per second will also be less on account of the movement of the buckets. But as new buckets constantly intercept the path of the jet, the total amount of water effective is equal to the total discharge of the jet, hence, from equation (7),

$$F = (1 - \cos\alpha)\,\frac{q\,w\,v}{g}\,(1 - \phi) \qquad (11)$$

The energy E expended on the buckets per second is equal to the force, F, times the distance, ϕv, through which it acts, *i.e.*,

$$E = F \phi v = (1 - \cos \alpha)(1 - \phi) \frac{q w v}{g} \phi v \qquad (12)$$

This is a maximum when $(1 - \phi) \phi$ is a maximum or when $\phi = 0.5$. Substituting $\phi = 0.5$ and $\cos \alpha = 180$ deg. above, we then obtain

$$E = \frac{q w v^2}{2 g} \qquad (13)$$

In an impulse wheel, it is not practicable to change the direction of the water through 180 deg. as it would then interfere

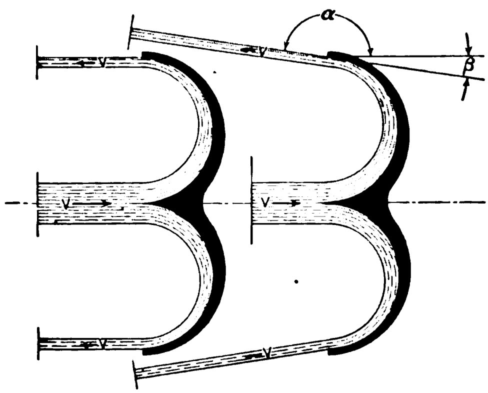


FIG. 4.—JET DIVERGING 180 DEGREES.

with the succeeding bucket. The angle $\cos \alpha$ must therefore be less than 180 deg., but the loss from this source is small, probably not more than 0.5 per cent.

Fig. 5 illustrates graphically the flow of water into and through the bucket of a tangential wheel at the most economical relative velocity. The bucket is double, each half being essentially semicircular in section. v is the absolute velocity of the jet; v' is the absolute velocity of the bucket; v_r is the relative velocity of the jet in relation to the bucket; or, $v_r = (1 - \phi) v$. The bucket is moving in the direction $B\ B'$ and occupies successively the positions indicated by the vertical lines a, a_1, a_2, etc., in equal intervals of time. The water moves along the surface of the bucket with a uniform velocity, v_r, passing successively through

equal distances, indicated on the surface of the bucket by the lines b, b_1, b_2, etc., in equal intervals of time.

At each of these successive points the jet has changed its direction and its absolute velocity. Its path through space is represented by the line $B\ C\ D$. The change in velocity is represented by the absolute velocity curve, $E\ F$, in which ordinates are the resultants obtained by applying the principle of triangle

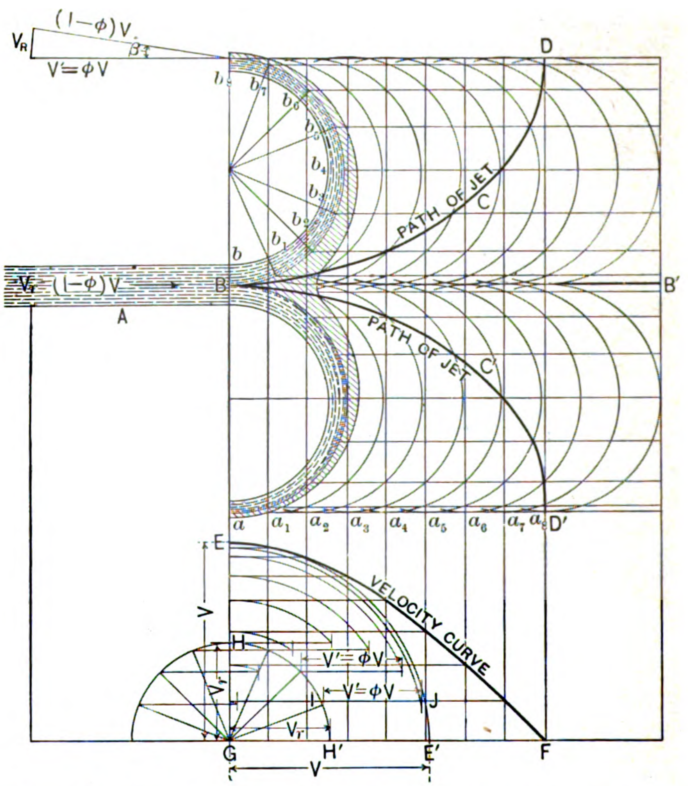


FIG. 5.—GRAPHICAL ILLUSTRATION OF FLOW IN TANGENTIAL BUCKETS.

of velocities to corresponding velocities of the bucket and of the water relative to the bucket.

At the time of entering the bucket the stream has the absolute velocity, v, represented by the length of the line $G\,E$ and $G\,E'$, in the lower diagram, while its velocity relative to the bucket is constant and equal to v_r, equal to the length of lines $G\,H$ and $G\,H'$. For the most effective speed, $v_r = v/2$.

At the end of the first interval of time, the jet has moved from the original point of contact with the bucket, b, to the position b_1. Its direction and velocity in the upper half of the bucket are represented by the radius $G\,I$ in the lower velocity diagram. $v' = \phi\, v$, is constant both in magnitude and direction, and this is laid off in the lower diagram on the line $I\,J$. The resultant of these two velocities is represented by the line $G\,J$ which is the absolute velocity of the water in space, and to indicate the velocity of the water at this instant is laid off for the purpose of the velocity diagram on the ordinate a_1 from the axis $G\,F$ in the lower diagram. In the same manner each of the remaining points on the velocity curve $E\,F$ is constructed. The jet leaves the bucket as shown with a velocity, relative to the bucket, of $(1 - \phi)\, v$. If this velocity is combined graphically with the velocity of the bucket $\phi\, v$, the true absolute residual velocity v_r of the water will be obtained. The efficiency is evidently maximum when ϕ has a value with v_r a minimum. This condition can be shown to obtain when the triangle is isosceles or when $\phi_v = (1 - \phi)\, v$ which gives $\phi = 0.5$.

The hydraulics of the tangential wheel has been discussed somewhat at length on account of its simplicity. If the friction of water and air on the bucket could be obviated, and if the friction of moving power could be eliminated, the runaway speed of the wheel would be equal to the spouting velocity of water, which in turn is slightly less than $\sqrt{2\,g\,h}$ on account of nozzle and atmospheric friction. In practise, therefore, the runaway speed of the tangential wheel is less than $\sqrt{2\,g\,h}$, *i.e.*, $\phi_{max.} < 100$. In consequence of these friction losses, it was also found in the case of the small experimental tangential wheel that the values of $\phi_{max.}$ vary considerably with different heads under which the experiment was conducted. (See Table I.)

The value of $\phi_{max.}$ apparently increases with the head somewhat to about 73 feet, on account of the relatively large friction loss at the lower heads, and then decreases somewhat to the maximum head, probably on account of the less efficient action of the larger quantities of water discharged from the jet onto the buckets at the higher head. These results should probably vary with the quantity of water for which the bucket is designed. In the tangential wheel the wheel diameter should be measured between the center lines of the bucket, on which lies the center of the application of the resultant of the combined stream lines of the jet. The peripheral velocity

of the wheel measured on this line of application can never move faster, theoretically, than the spouting velocity of the water, and practically is reduced by friction and windage from 10 to 20 per cent or more below this velocity.

Table II shows the result of various tests which have been made on tangential wheels. In this table is given as determined by experiments, the runaway speed ratio, $\phi_{max.}$, the most efficient speed ratio, ϕ_e, and the values of ϕ both higher and lower than ϕ_e at which the efficiency of the wheel was 5 per cent below the maximum efficiency of the speed ϕ_e. Below each value of ϕ the percentage that value bears to $\phi_{max.}$ is given. It should be noted that any cause that reduces efficiency reduces $\phi_{max.}$ as for example, the use of flat buckets in experiment No. 7.

TABLE I

RUNAWAY SPEED OF 12-IN. DOBLE TANGENTIAL WHEEL AT VARIOUS HEADS

Head	Rev. per sec.	$v = \sqrt{2gh}$	v'	$\phi_{max.}$
13.3	7.4	29.25	23.28	0.796
25	10.14	40.1	31.62	0.79
36.6	12.63	48.52	39.8	0.82
49.4	14.77	56.37	46.5	0.825
61	16.45	62.55	51.7	0.826
72.6	17.92	67.25	56.5	0.842
83.9	19.45	73.4	61.4	0.838
95.3	20.81	78.3	65.5	0.837
108.3	22.05	83.5	69.4	0.832
118.7	23.05	87.5	72.5	0.829
130.1	24.25	91.5	76.4	0.835
141.9	25.4	95.5	80	0.8385
153.5	25.61	99.5	80.6	0.811
165.1	26.59	106	83.5	0.787

It is evident that the diameter of the wheel may be measured on some other circumference than that on which the center of the jet is applied. If, for example, a rim or extension were added to the wheel beyond the bucket, or if the buckets themselves extended considerably beyond the center of pressure, and if the diameter and peripheral velocity of the wheel is measured at any such exterior circumference beyond the line of application of the jet, the peripheral velocity so measured will be found to be materially greater than if measured at the bucket centers. The peripheral velocity so increased may be so great that the resulting value of $\phi_{max.}$ will equal or exceed the spouting velocity of water or 1. In reaction wheels such conditions actually obtain.

TABLE II
RELATION OF SPEED RATIOS UNDER OPERATING AND RUNAWAY CONDITIONS

Tangential Wheels

Wheel tested	Where tested	Bucket	Diam. of wheel	Diam. of nozzle	Head	Value of ϕ for Relative efficiency −5%	ϕ_e	−5%	Runaway ratio ϕ_{max}.	Remarks
B-M	Univ. of Mich.*	Backus	18 in.	¾ in.	113.88 ft.	0.352 179.5%	0.445 141.8%	0.512 123.3%	0.631	
Univ. of Mich. motor	Univ. of Mich.*	De Puy	14.74 in.	⅝ in.	97.02 ft.	0.345 227.3%	0.465 168.7%	0.545 143.9%	0.784	Nozzle angle 0°, face angle 30° 30 buckets.
L-C	Univ. of Mich.*	Leffel	12 in.	½ in.	69.2 ft.	0.316 268.3%	0.404 209.8%	0.499 170%	0.848	Nozzle angle 10.75° 13 buckets
H	Univ. of Mich.*	Hug	24 in.	1 in.		0.38 205.1%	0.46 169.6%	0.525 148.6%	0.78	
Univ. of Mich. motor	Univ. of Mich.*	Doble	14.6 in.	½ in.	about 230 ft.	0.341 219.2%	0.397 188.4%	0.476 157%	0.747	
A-D	Univ. of Wis.†	Doble	12 in.	⅞ in.	13.3 to 165.1 ft.	0.326 254%	0.443 186.9%	0.554 149.5%	0.828	
Univ. of Mich. motor	Univ. of Mich.*	Flat	15 in.	¾ in.	92.4 ft.	0.244 283%	0.342 202%	0.468 147.6%	0.691	Nozzle angle 8° 24 buckets
P	Univ. of Mich.*	Pelton	12 in.	¾ in.	181.6 ft.	0.326 270.8%	0.508 173.5%	0.593 148.6%	0.882	
P	Univ. of Mich.*	Pelton	12 in.	½ in.	173.2 ft.	0.398 226%	0.482 186.5%	0.532 169%	0.90	
P	Univ. of Mich.*	Pelton	18 in.	½ in.	206.28 ft.	0.362 243.5%	0.43 205%	0.528 167%	0.881	
P	Univ. of Mich.*	Pelton	18 in.	¾ in.	112.73 ft.	0.344 260%	0.44 203%	0.586 152.4%	0.894	
P	Univ. of Mich.*	Pelton	18 in.	1 in.	68.68 ft.	0.391 218.8%	0.518 165%	0.621 137.6%	0.855	

*From Michigan Technic, Vol 19, No. 2.
†From University of Wis. Bull. No. 337.

The curves of the reaction bucket are so complicated that the center of application of the resultant pressures cannot be accurately determined. The diameters of reaction wheels are therefore measured on the outer diameter of the buckets and consequently outside of the center of application of forces, as above discussed. The result is that the value of ϕ_{max} in the reaction wheels is greater than unity.

The relative values of ϕ_{max}. in the various types of reaction wheels are further complicated by the fact that the outer diameter of the runner may vary at different points, and that even when the runners of various makers are of similar design, the same size of wheel may be measured at different points, and consequently, be listed as of different diameter. In general, the section of reaction of wheel may be represented by the two outlines in Fig. 6, and in practise are measured on the various lines marked D, D', D'', D'''.

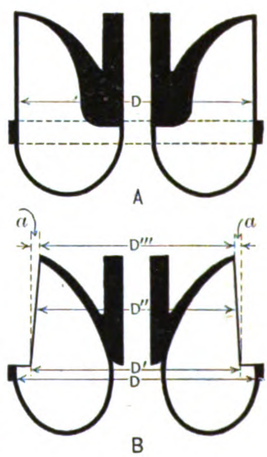


Fig. 6.

American practise, in the measurement of turbine waterwheel diameters, as far as I have been able to determine, is given in Table II.

Hydraulics of the Reaction Turbine

The hydraulics of the reaction wheel, on account of a more complicated curvature of the buckets, is apparently more involved. The reaction wheel is, however, subject to essentially the same principles, although their application is somewhat more obscure.

The velocity of the water through the buckets of the reaction turbine is less than in the tangential wheel, and the energy of the water is delivered through pressure instead of through impact. The energy in both cases is delivered through the reactive pressure, due to a change in the direction of the water jet through contact with the surface of the bucket of the turbine, and in the reaction wheel the conditions are also essentially as shown in Fig. 5.

If the reaction wheel could be measured on the diameter of the circumference at which the resultant of the active jets of water is applied, the resulting velocities would closely approximate those of the tangential wheel.

On account of the diversity in practise in the measurement of the diameters of reaction turbines, and also on account of the diversity of this design, a general statement of the value of ϕ_{max} cannot be made, for this value varies considerably in the different makes of turbine water wheels. Reaction wheels vary greatly in design and may be roughly classified as low speed,

TABLE III

PRACTISE OF VARIOUS AMERICAN MANUFACTURERS IN MEASURING AND CATALOGING THE DIAMETER OF TURBINE WATER WHEELS

Manufacturer	Type of runner	Style	Point of measurement
A-C		*B*	*D''*
D-G	A	*A*	*D*
	N-A	*A*	*D*
	S-A	*B*	*D''*
	I-A	*B*[1]	*D'*
R-H	Mc[2]	*B*	*D*
	H	*A*	*D*
J-L	S-L	*A*	*D*
	Sp-L	*A*	*D*
	S	*B*	*D*
	I-S	*B*	*D*
J	Mc	*B*	*D''*
P-I	Type A	*B*	*D'*
	Types B and C	*A*	*D*
M-S	Mc[3]	*B*	*D'*
	S	*B*	*D'*
T	S-T[4]	*B*	*D' ''*
	H-T	*B*[5]	*D*
W-S		*B*	*D''*

1. Fillet at angle. Diameter measured just above.
2. Diameter of runners as measured at the crown which projects beyond the tips of the buckets and is essentially the same in diameter as at *D'*.
3. Diameter of the runners as measured at the crown which projects beyond the tips of the buckets and is essentially the same in diameter as at *D'*.
4. Diameter at *D* is 20 per cent greater than at *D' ''*.
5. Bucket of high speed runner has parallel edges but is cut back as shown in *B*.

moderate speed, and high speed wheels. In the low speed wheels, the values of ϕ_e which will result in the greatest efficiency will vary perhaps from 0.60 to 0.70; for moderate speed from 0.70 to 0.80, and for high speed, from 0.80 to 0.90. This, however, is a general statement and others might not agree to the exact limits of values given. In each case the actual speed of the wheel under the conditions of operation should be determined and the

maximum speed which may possibly obtain. When the runaway speed of the water wheel is definitely known and the value of ϕ_e at which the water wheel will operate under fixed head is also established, the relation of the operating to the runaway speed can be definitely determined and the deduction drawn as to the necessary strength of the rotary machinery to be operated thereby. In many cases, however, the head under which the turbine is to operate is not fixed but varies between conditions of extreme high water and conditions of extreme low water. In low head plants the head is normally much greater under low water conditions and much less during flood conditions. This variation may in some cases be relatively great. In ordinary practise it is not unusual for the minimum head to be 50 per cent of the maximum head. In such cases, the relative speed of the wheel will vary in its relation to the spouting velocity of water inversely as the square of the head; and in the case mentioned, will vary essentially as 10 is to 7; that is to say, where the minimum head is one-half of the maximum and the wheel is operating at a uniform speed, the value of ϕ will vary under different conditions, for example, from 0.49 to 0.70, 0.56 to 0.80, 0.63 to 0.90, or 0.70 to 1. In many modern turbines, such ranges of relative speed are possible with fairly good resulting efficiency. In such cases, the most satisfactory relative speed and practically the highest efficiency will be reached at a point intermediate between the extremes given. Under such conditions, the relative operating speed of wheels under conditions of high head is much lower than under the best conditions, and under low head is much higher than for the best conditions, and if the turbine should overspeed during periods of high heads, the relative increase in speed due to the runaway condition will greatly exceed that which would obtain under normal conditions or under low head conditions. In order to form a basis for an intelligent estimate of the relation of the runaway speed of wheels to the operating speed under the conditions outlined, I have prepared Table IV showing the results under test of various types of reaction water wheels on which experiments have been made. In this table is given the value ϕ_{max} corresponding to the runaway speed as determined by experiment, also the value ϕ_e at which the maximum efficiency was secured. There is also given the variations in ϕ at which the wheels operated with 5 per cent less efficiency both above and below the most economical speed. These variations in ϕ correspond approximately to those required for the 50 per cent

TABLE IV. RELATION OF SPEED RATIOS UNDER OPERATING AND RUNAWAY CONDITIONS

Reaction Wheels							
Manufacturer	Holyoke test number	Diam. of runner	Values of ϕ for relative efficiency			Runaway ratio ϕ_{max}	Remarks
			−5%	ϕ_e	−5%		
W-S	1795	32 in.	0.563 218%	0.738 153%	0.826 148.4%	1.225	Feb., 1909
W-S	1796	28 in.	0.675 180%	0.800 151.9%	0.965 126%	1.215	Feb., 1909
W-S	1797	30 in.	0.681 181.6%	0.782 158.1%	0.961 128.7%	1.238	Feb., 1909
W-S	1799	31 in.	0.640 190.4%	0.755 161.2%	0.874 139.4%	1.218	March 1909
W-S	1800	31 in.	0.669 192.2%	0.781 164.5%	0.943 136.2%	1.285	March, 1909
A-C	1778	30 in.	0.668 203.2%	0.815 166.6%	1.012 134%	1.358	
A-C	1883	30 in.	0.613 217.5%	0.75 177.5%	0.896 148.6%	1.332	
A-C	1815	45 in.	0.691 183.8%	0.815 155.8%	0.987 128.6%	1.270†	†0.9 gate
M-S	1983	30 in.	0.629 188.9%	0.767 155%	0.848 140%	1.188	Feb., 1911
M-S	1820	48 in.	0.631 194%	0.75* 162%	0.930 131.5%	1.224	June 1909
J-L	1690	45 in. (38½ in.)*				1.412 (1.21)†	Sept., 1907
J-L	1903	50 in. (43½ in.)*		0.868 157.2%		1.365 (1.19)†	
J-L	1896	35 in. (30½ in.)*		0.899 156%		1.40 (1.22)†	April, 1910
D-G	1509	44 in.	0.652 192%	0.781 160%	0.932 134.1%	1.250	March, 1904
D-G	1835	60 in.	0.639 198%	0.759 166.4%	0.937 134.9%	1.263	Aug., 1909
J. B. Francis Fourneyron turbine‡		113 in.	0.44 356%	0.75 209%	0.101 155%	1.566	See Water Power Engineering p. 703
R		48 in.	0.54 190%	0.68 150.5%	0.79 129.5%	1.023	See Water Power Engineering, p.704
H-M	988	42 in.		66.5 168%		1.120	See Water Supply and Irrigation paper U.S.G.S No. 180 p.60.
H-M	1030	45 in.		66.5 169%		1.124	See Water Supply and Irrigation paper U. S. G. S., No. 180 page 60.
H-M	1077	51 in.		67.7 170%		1.151	See Water Supply and Irrigation paper U. S. G. S., No.180 page 64

NOTE. Percentages show relations of runaway to operating speeds.
*These diameters show the corresponding size of the wheel measured at the center of the gates and value of ϕ_{max}. marked † show the values calculated on these diameters.
‡No longer manufactured.

range in heads discussed above. In each case the percentage of ϕ_{max} to the operating value of ϕ is given just below the value in question. This percentage, in both Tables III and IV, shows the relative speed for which attached machinery must be designed to meet runaway conditions if operated at ϕ_e or under the two extremes given.

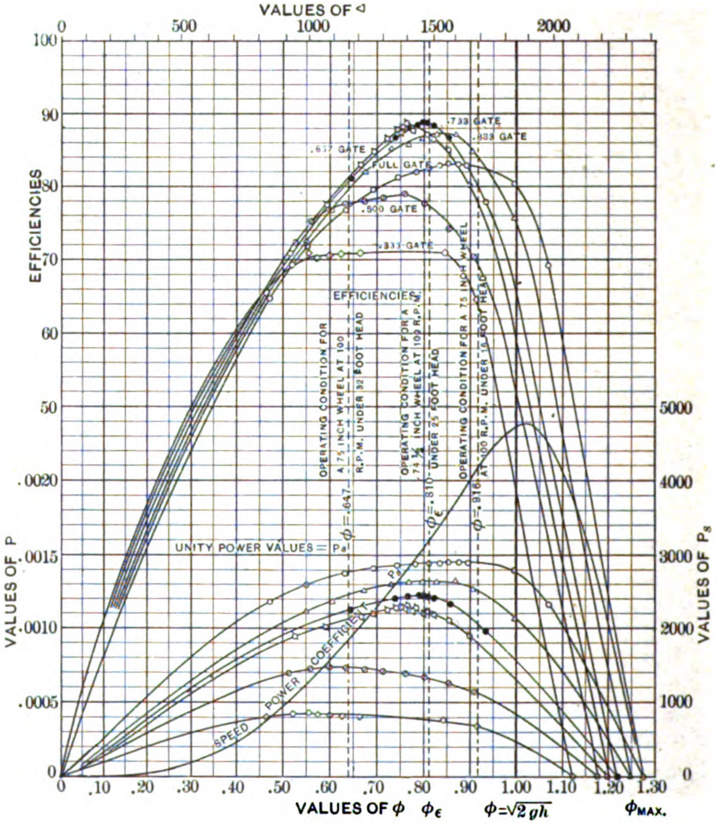


FIG. 7.

For the J–L wheels the values of ϕ are calculated both for the table diameter and also for the actual diameter measured at the center of the gates. From a comparison of these values it will be noted that while the speed of these wheels seems unduly high when based on the maker's measurements they actually correspond closely with other standard wheels when based on the diameter measured at the gate centers.

From Tables II and IV some general conclusions can be drawn, but as in most problems of this class, general statements are apt to be misleading, and the speed problem should be carefully analyzed for each particular case.

As a brief example of such wheel analysis, the writer has considered a single type of wheel under various conditions of use. Fig. 7 shows a complete graphical record of the W–M test (No. 1800) of a 31-in. reaction turbine, so analyzed that all of the fundamental data for power, speed and efficiency are given for any wheel of homologous design, or identical in type regardless of size, as well as for the particular wheel on which the experiments were made.

In this diagram are given the values of

The efficiency of such wheels at various relative speeds.

ϕ = the ratio of peripheral to spouting velocity.

$\triangle$ = the speed at one-foot head of a one-inch wheel of homologous design.

$\mathcal{P}$ = the power under one-foot head, of a one-inch wheel of homologous design.

$\mathcal{P}_s$ = the speed power coefficient.

The value of $\mathcal{P}_s$ is expressed by the equation

$$\mathcal{P}_s = \frac{n^2 P}{h^{5/2}} \tag{14}$$

This coefficient is the square of the coefficient of " unity speed" of the type of wheels considered, and is used in the above form to facilitate calculation for water power purposes.

It should here be noted that in general, when the coefficients of a series of wheels of homologous design are given, they are given for the condition of maximum efficiency, and maximum efficiency can only be obtained by operation under the fixed value of ϕ_e or $\triangle_e$.

Any wheel, however, may be so installed or operated that ϕ or $\triangle$ may vary from 0 to maximums which are approximately

$$\phi_{max} = 1.28$$

$$\triangle_{max} = 2400$$

In consequence $\mathcal{P}$ will vary from 0 with $\phi = 0$ to an approximate maximum with ϕ_e and then to 0 again with ϕ_{max}

Efficiency will vary in essentially the same manner.

As $\mathcal{P}_s$ varies with the square of the speed and directly with the power at full gate, it also varies from 0 with $\phi = 0$ through a maximum to a value of 0 at ϕ_{max}. The maximum value of $\mathcal{P}_s$ does not occur with ϕ_e as will be noted from Fig. 7.

In many series of wheels of homologous design the following principles hold within the limits of error due to imperfect design, construction and installation.

Where ϕ is held at a constant value:

Efficiency will remain constant for any given gate opening

$$\frac{D\,n}{\sqrt{h}} = \frac{D_a\,n_a}{\sqrt{h_1}} \tag{15}$$

i.e., the rev. per min. varies directly with $\sqrt{h}$ and inversely with the diameter of the wheel.

$$\frac{P}{D^2\,h^{3/2}} = \frac{P_a}{D_a^2\,h_a^{3/2}} \tag{16}$$

i.e., the power of wheels varies directly with D^2 and with $h^{3/2}$.

With wheels of the same diameter and with ϕ held at a constant value

$$\frac{n}{\sqrt{h}} = \frac{n_a}{\sqrt{h_a}} \tag{17}$$

The rev. per min. of a wheel varies directly with $\sqrt{h}$.

$$\frac{P}{h^{3/2}} = \frac{P_a}{h_a^{3/2}} \tag{18}$$

The power of a wheel varies directly with $h^{3/2}$

The following relations also obtain:

$$\phi = \frac{v'}{v} = \frac{\triangle}{1842} = \frac{D\,n}{1842\,\sqrt{h}} \tag{19}$$

$$P = \mathcal{P}\,D^{3/2} \tag{20}$$

$$P = \frac{\mathcal{P}_s\,h^{5/2}}{n^2} \tag{21}$$

Referring to Fig. 7, it is evident that the maximum efficiency may be obtained from this series of wheels when $\phi_e = 0.81$ and $\mathcal{P}_s = 3200$.

If we desire to secure 1000 h.p. with a wheel of this type at 25-foot head and 100 rev. per min.

$$n_1 = \text{speed at one-foot head} = \frac{n}{\sqrt{h}} = \frac{100}{\sqrt{25}} = 20.$$

$$P_1 = \text{power at one-foot head} = \frac{P}{h^{3/2}} = \frac{1000}{125} = 8.$$

$$\mathcal{P}_s = n_1^2 P_1 = 3200.$$

This shows that a wheel of this series will operate under these conditions to the best advantage.

The size of the wheel can then be determined as follows:

$$D = \frac{1842\ \phi}{n_1} = 74.5 \text{ inches} = \text{diameter of wheel.}$$

$$\frac{\phi_{max.}}{\phi_e} = \frac{1.275}{0.81} = 157 \text{ per cent} = \text{relative runaway speed.}$$

Runaway speed = 157 revolutions per minute.

If we desire to operate a wheel of this type and of 75-in. diameter under conditions where the head will vary from 16 to 32 ft. under various conditions of river flow, a somewhat different problem must be considered. With $\phi_e = 0.81$ and $h = 32$, a 75-in. wheel would run at 113 rev. per min. and would give 1470 h.p. at full gate.

With $\phi = 0.81$ and $h = 16$, a 75-in. wheel should run at 80 rev. per min. and give 520 h.p. In order to run at both heads with reasonable satisfaction a constant and intermediate speed must be selected, which from trial appears to be $n = 90$.

Under this condition

$$\text{with } h = 16,\ \phi = \frac{75 \times 90}{1842 \times 4} = 0.916;\ \mathcal{P}_s = 4100;\ P = 520.$$

$$\text{with } h = 32,\ \phi = \frac{75 \times 90}{1842 \times 560} = 0.647;\ \mathcal{P}_s = 1900;\ P = 1270.$$

Under these conditions the power and efficiency is considerably reduced at 32-ft. head, which may, however, be warranted by the condition.

Under the above conditions the runaway speed at the 32 ft.-head will be

$$\frac{\phi_{max.}}{\phi} = \frac{1.275}{0.647} = 197 \text{ per cent} = 177 \text{ rev. per min.}$$

In this manner the actual runaway speed can be ascertained with any given wheel and under any condition of head. It should be noted, however, that the results may be modified somewhat by various physical conditions.

1. The value of ϕ_{max} under high heads may increase somewhat over that determined by tests given above on account of the fact that the friction does not increase as rapidly as the power under increased heads.

2. The value of ϕ_{max} will decrease slightly when the turbines are directly connected to generators on account of the power necessary to move the same when running light.

The writer can offer no data on which to estimate these changes in ϕ_{max}. but such changes are not large.

Conclusions

From an inspection of Table II it will be seen that in the case of impulse or tangential wheels which are used under high heads, which heads are generally relatively constant, the over-speed to be cared for should be estimated at 100 per cent of the normal speed.

In general, from an inspection of Table IV, it may be stated that when a reaction turbine is working at the most efficient speed ratio (ϕ_e) and the head is constant, the runaway speed (ϕ_{max}) may be as low as 150 per cent or as high as 180 per cent of such speed, according to the type of wheel used, or, otherwise, that the overspeed may be from 50 to 80 per cent above the normal speed of a reaction wheel. If, however, under the low head condition there is wide variation in the head available under different conditions of stream flow, and if the wheel is designed to work under these various conditions, and the speed chosen is intermediate to that which would be chosen under either extreme, then, under the maximum head a runaway speed of 200 per cent or more of the normal speed may be realized.

These conclusions are only general, and in all cases a detailed analysis should be made, based on test data for the particular type of wheel which is to be used, and considered for the extreme range of heads and the exact conditions which must be anticipated.

A paper presented at the 29th Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June 28, 1912.

RELAY PROTECTIVE SYSTEMS

BY L. L. ELDEN

Reviewing American practise in the use of relay protective devices for electrical generating, transmission and distributing systems, there appears to have been no material change in the construction or commercial application of this class of apparatus in a considerable period of years.

Such improvements as have been made relate principally to mechanical details for increasing the reliability of operation and maintenance of adjustment of relay apparatus. Recently, in response to demands for modifications of the electrical characteristics of time limit overload relays, certain changes have been made in existing types of relays, and in addition a new type of relay has been introduced. These developments have tended to greatly increase the facilities for obtaining selective action between different relays in stations where such operation of relays is desired.

Experience has shown that no single part of an electrical system is free from the possibility of injury, either accidental or unavoidable as may be the case, and that it is incumbent upon operating and designing engineers to protect their systems as far as possible from such occurrences, through the use of protective devices suitably designed to afford such protection.

We may summarize American practise in the application of relay protection to the various parts of alternating-current electrical supply systems of moderate and large capacities as follows:

Generators. In general, generators are not arranged for automatic disconnection from the system which they supply, upon the occasion of a fault developing within their windings or their

connections to the main buses. Reverse current relays are used in many cases to operate signals to indicate reversal of current in generator circuits, but under all conditions the judgment and movements of the operator are usually depended upon for the proper operation of generator switches.

Transmission Lines. Relay protection for transmission lines varies with type and method of operating different systems, but in general either instantaneous, inverse time limit or definite time limit types of relays have been used according to engineering judgment.

In systems operating radial feeders, with each feeder connecting to only one substation and not operated in parallel at substation ends, reasonably satisfactory service has been rendered by the types of relays referred to.

In systems operating ring systems of feeders, or radial feeder with several substations in tandem on a single feeder, where selective adjustments are required between different relays in order to prevent interruption of service from all stations between a fault and the source of power, satisfactory results have rarely been continuously attained with any of the types of relays mentioned. In attempting such operation recourse has been had to reverse current relays in combination with time limit overload relays, with equally unsatisfactory results.

In addition to these regular or standard methods of employing relays for line protection, many attempts have been made to devise arrangements for cutting a defective feeder out of service from among a group of feeders operating in parallel at both ends, without affecting the remaining feeders. Combinations of reverse current and time limit relays have been used for this purpose, arranged with interlocking attachments to prevent other than faulty feeders being affected.

It may fairly be said that indifferent success has uniformly been the result of the use of such arrangements, due in some part to the failure of the apparatus itself to consistently and continually operate as designed, and in other ways the apparatus has failed to meet the conditions developed by faults. There are of course some instances where radial systems of transmission lines have operated with reasonable satisfaction using some form of standard relay for protection, still, it is well known that failures have been experienced through faults inherent in the relays themselves, thereby producing a feeling of uncertainty as to their operating condition at all times while in service.

Recourse has been had to frequent inspection and tests to prevent failure in service, all of which creates undesirable expenditure for maintenance without adequate return in security from failure.

Putting the situation plainly, the standard relay devices in use in our alternating-current systems are inadequate to properly protect the apparatus they are intended to protect, simply because they do not discriminate between faults and excess current conditions.

It is probable that very few engineers on this side of the water appreciate the great difference between American and European practise in the use of relay protective devices. Articles have appeared in the technical press from time to time in which brief comment has been made in reference to certain developments and applications of protective systems in England and on the Continent, without, however, attracting the attention they deserved.

A personal inspection of some of the larger European undertakings reveals substantial advances in the art of relay protection which, as applied to generators—sections of bus bars—transmission lines and substation apparatus, have operated with marked success. Several systems have been developed which possess merit, but among them all the system invented by Messrs. Merz and Price of London, England, is apparently the most flexible and best adapted for application to any of the problems of such a character as are met with in the protection of the various apparatus and connecting links comprising electrical supply systems.

This form of protection has proved so reliable in practise that it has become not only safe, but possible, to operate high-tension interconnected transmission systems without risk of the failure of a single section interfering with the remainder of the system. Individual ring feeders may not only be cross connected at will, but may with perfect safety be interconnected with other ring or radial feeders as desired, either for reasons of capacity or insurance of service to consumers. The economic advantages resulting from such use of investment, particularly in systems covering wide areas, are too obvious to require comment. The extent to which the interconnection of feeders and generating stations is carried out in regular service is indicated in some measure by reference to Fig. 1, in which is shown a typical arrangement of interconnected high-tension feeders.

This system of protection has the further advantage of being

discriminative in action, operating only under fault conditions and possessing the further valuable characteristics of cutting out defective apparatus instantly, or while troubles are in the incipient stage, thus preventing the destructive aftermath which sometimes follows minor troubles if allowed to develop to serious proportions. Its introduction and subsequent use has modified foreign practise to such an extent, that there is a strong tendency

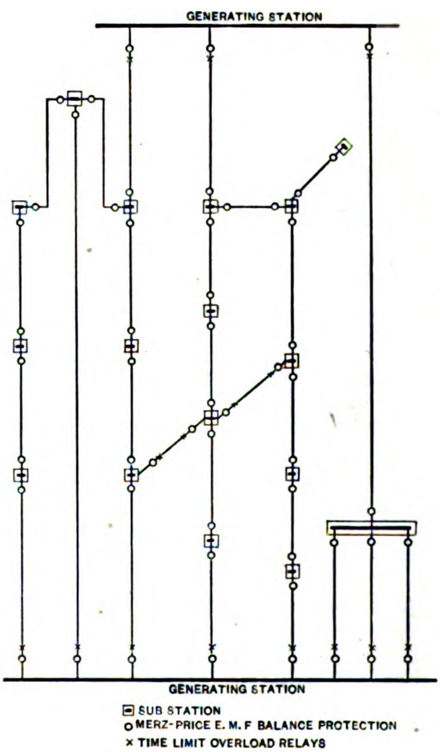


FIG. 1.—TYPICAL ARRANGEMENT OF RELAY PROTECTION WITH MERZ-PRICE SYSTEM.

to apply the system to generator protection in many new installations, while some important companies are adopting this system for the protection of existing generating and transforming apparatus.

The Merz-Price system of relay protection is based on the principle that if a conductor in service is in a sound condition the current entering and leaving it must be of the same value,

due allowance being made for losses. It will thus be apparent that such a system is capable of being arranged for the protection of any generator, section of busbar or transmission line, by introducing suitable relay equipment at the proper points.

The apparatus employed in this system consists of suitably designed series transformers and relays, and, in addition, pilot wires forming a connecting link between the relay apparatus located at the terminals of the protected section of line.

The limitations of the system lie mainly in the first cost and construction incident to the installation of the pilot wires, the remainder of the apparatus or its application being no more costly and at the same time far simpler than the devices which we regularly use for similar purposes. In the commercial use of this system two standard arrangements of the apparatus are generally employed, although many other combinations may be arranged for special purposes. These two standard arrangements are designated as "current balancing" and "potential or e.m.f. balancing." "current balancing" is usually employed for the protection of generators, transformers, frequency changers etc., while "e.m.f. balancing" is used in connection with feeder protection where the energy losses in the pilot wires makes the current balancing scheme undesirable. In addition another development is called the "magnetic balance system" which has its application in similar locations to those in which current balancing is used.

Fig. 2 illustrates the principles of these three arrangements of protective devices in which

A represents the "current balance system" applied to the protection of a transformer.

B represents the "e.m.f. balance system" applied to feeder protection, and

C represents the "magnetic balance system" applied to transformer protection.

In *A* it will be noted that series transformers are installed on both primary and secondary sides of the main transformer. The series transformers are of such ratios that their secondary currents are equal at all loads on the main transformer, and are connected with their secondaries in series, with the current flowing in the same direction through the secondary circuit. Suitable pilot wires are employed to complete a relay tripping circuit with the relays connected to the central points of the secondary circuit as shown. As the connection of the relay circuit to the

secondary circuit is made at the point of zero potential, no current flows in the relay circuit so long as the current in the main conductors and therefore in the secondaries of the series transformers, remains balanced or in the same ratio. Any variation in this current balance results in a flow of current through the relay circuit, thus causing the relays to operate to open the main switches on both sides of the main transformer, upon the unbalance reaching predetermined values for which the relays

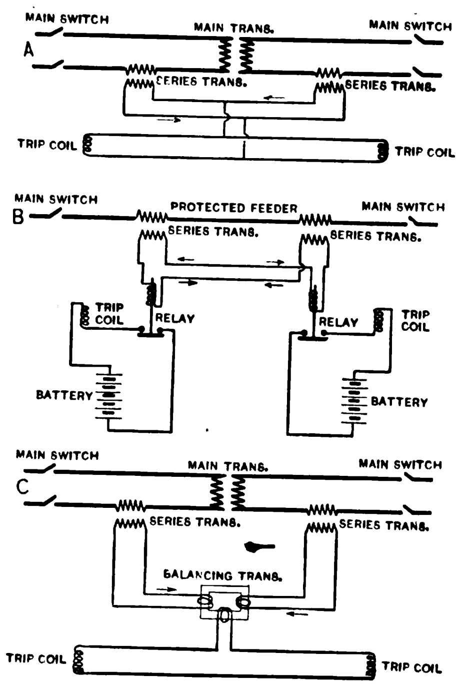


FIG. 2.—TYPICAL ARRANGEMENTS OF MERZ-PRICE PROTECTIVE SYSTEM.

may be adjusted. Series transformers of any standard design are suitable for use with this scheme of protection, providing, however, they are of sufficient capacity to furnish the necessary current to overcome the resistance of the pilot wires and trip coils as well as their own impedance. What is more important, they must maintain their own ratio with great accuracy under extreme overloads, otherwise the relays may be operated at times unnecessarily, through the difference in secondary currents delivered by the protective transformers under the same load.

B illustrates the " e.m.f. balance system " as applied to a single feeder. Series transformers are used as in the preceding case except that in this system they are connected with their secondaries opposed or bucking, under which conditions no current flows in the secondary circuit as long as the current in the main conductor is normal throughout the protected section. Upon this balance becoming affected, the difference in potential thus created between the series transformers will force current through the secondary circuit and actuate the relays included in that circuit, to close the trip circuit and open the main switches. Series transformers for the " e.m.f. balance system " must usually be of special design as most types of standard transformers cannot be operated on open circuit without burning out. These transformers must be designed to operate with a low temperature rise, and be of ample capacity to supply the energy necessary to overcome the resistance of the pilot wire and relay circuit. What is most important, they must be able to maintain exact ratios of transformation under all conditions of load, including extreme overloads. Substantial insulation must be provided between secondary turns in these transformers to successfully withstand the high potentials developed by heavy rushes of current in the main conductors when occasioned by faults elsewhere in the system, or by the heavy starting currents of motors of large capacity.

C illustrates the " magnetic balance system " as applied to the protection of a single transformer. The series transformers are arranged with their secondary circuits connected to a balancing transformer provided with a one to one winding. As the series transformers are designed for equal secondary currents with relation to the ratio of the main transformer, the resultant flux in the core of the balancing transformer is zero and no current will flow in the winding connected to the trip circuit, so long as the main transformer is in sound condition. Upon the occurrence of a fault within the main transformer, the current in the secondary circuits of the series transformers will become unbalanced, resulting in an induced potential in the trip circuit windings, sufficient to operate the relays to open the main switches. Standard series transformers may be used with this system, providing they are of suitable capacity and of correct ratio. The addition of the balancing transformer may or may not offer advantages over the regular " current balance system " according to conditions, although it is to be noted that the latter system appears to be preferred in all recent installations.

Relays used with the Merz-Price system are of the simplest forms of the instantaneous type of circuit closing relay, capable of adjustment for different currents and arranged with time limit attachments when used for the protection of certain classes of apparatus such as generators or transformers. These time limit attachments are provided to prevent the opening of main switches by heavy rushes of current which may be developed when synchronizing generators, or switching large transformers into service.

Experience indicates that for reliability it is best to use a battery for operating the trip coils on switches, in preference to using alternating current trip coils directly in the secondary circuits of the system. The battery system requires series transformers of less capacity and makes certain that low voltage in the main system will not lower the secondary potentials to values insufficient to operate the trip coils.

Important as are the other features of this system, no less important is the part played by the main switches used in connection with these relay devices. A quick acting switch is a necessity if the full benefit of the action of the relay on minor faults is to be obtained.

That such switches have been developed is shown by the absence of serious damage to cables or their surroundings upon the occasion of cable failures, there being every evidence that such faults are cut out very early in their development. It should also be noted in this connection that the duties imposed on oil switches when used on systems provided with balance protection, are not nearly as severe as in situations where ordinary overload protection is provided, due to the early disconnection of defective equipment under conditions which require the actual rupture of relatively small amounts of current.

The remaining link to be considered to complete the connections between the several parts of this system is the pilot cable. Where employed with either overhead or underground construction a No. 12 B. & S. gage 3-conductor, lead covered paper insulated cable of low capacity is generally employed, although in some modifications of the standard methods of connection, only two pilot wires are used. In underground installations this cable is laid beside the main cable in the same trench in the solid system of construction, or is drawn into a separate duct where the drawing-in system of construction is used. Where used in connection with overhead

lines, a catenary suspension is provided for the pilot cable which is ordinarily attached to the poles or carrying structures at a considerable distance below the main conductors. In certain undertakings open wires have been used for pilot wires on overhead lines, but not with as satisfactory results as cable installations have shown, owing to the induced currents developed in the pilot circuit, due to proximity to the high-tension wires. These currents have caused relays to trip upon the occasion of disturbances in the system, when there was no trouble with the main conductor being protected. As previously stated, the first cost, installation and maintenance of the pilot wires is the serious drawback to this system, amounting to approximately $1000 per mile as far as the cost of underground construction is concerned, although varying conditions may make it possible to materially reduce this cost, when a number of cables are to be protected. It is obvious that the maintenance of the pilot cable is of no less importance than that of the main cable, as a break in the pilot wires immediately causes the relays to operate the main switches exactly as though a fault had occurred in the main cable. Troubles of this character are more liable to occur with overhead construction, owing to the exposed positions in which they are placed with respect to opportunities for malicious damage, or that resulting from the action of the elements.

The really excellent feature of the Merz-Price system aside from its extreme simplicity, is its ability to protect against faults in any part of a system, thereby permitting the operation of momentary and continuous overloads at the discretion of the operator, without fear of interruption from the operation of the relay devices.

This is a sharp contrast to American practise, where heavy momentary overloads are likely to cause interruptions of service unless special provisions have been made to the contrary, and in the case of continuous overloads special relay adjustments may be required.

The Merz-Price system may properly be termed a system of protection which makes possible for the first time the supply of continuous service in alternating-current systems, in that it makes possible the operation of ring systems of feeders, or systems of feeders operating in parallel at both ends, and at the same time insures the instantaneous disconnection of any faulty feeder or section of a ring feeder, without affecting the service of the balance of the system. In making this assertion it is

assumed that in the design of ring systems of feeders, the conductors forming each ring are of suitable capacity to carry the entire load in either direction, or that interconnection with other feeders will afford the same capacity.

Consideration of the value of a protective system such as is here under consideration naturally involves discussion relative to the desirability of using any one of several arrangements of transmission lines, that is, whether ring systems or radial systems of duplicate independent feeders, or combinations of both are most desirable. This is a question to be decided on its merits in each case, and has no particular bearing on the relay question as that is adapted to all, but it is fair to assume that in supplying service to any substation, more than one source of supply is desirable. In widely scattered districts it is apparent that a ring main will more economically serve such business, and at the same time afford full protection against failure of service. Conditions of supply in large cities usually require the delivery of large quantities of energy to individual substations, making it necessary to employ several feeders for each station, under which plan the radial system is adopted with each feeder carrying full load, with perhaps a duplicate feeder or equivalent capacity in reserve. In this case there can be no advantage in a ring system from any point of view. Certain companies employing duplicate radial feeders with a number of substations in tandem, would obviously greatly improve the capacity and reduce the losses in their systems, if such lines were operated with their ends in parallel at the most distant substation, or possibly at other substations as well.

The fact remains that this system provides opportunities for operating economies in substations which at first glance may not be appreciated. It is not unusual to find many English substations in service without attendance of any character, where the Merz-Price system of protection is employed for the protection of feeders and apparatus. This is possible in transformer substations located on consumer's property, where energy is sold in bulk to a consumer through step-down transformers, without regulation or further attention. Under such circumstances if the main switches on a ring main and the transformers supplying the service are protected by this system of relays, it is obvious that a certain number of such stations in a system require no operators, and no unfavorable conditions will result to the consumer from their absence, providing the transmission system is properly designed and the consumer's own equipment is protected by suitable overload devices.

It is evident that a switch failure or short circuit on the station bus bars is a form of trouble to which the balance system of protection is applicable with satisfactory results. It is noted in actual practise, however, that owing to the success attending the operation of oil switches in the protection of feeders and station apparatus, the need for special protection for bus bars is rarely recognized in commercial operations.

While mention has been made of the simplicity of the relays, it is not to be inferred that a certain amount of care and testing is not required for their maintenance. On the contrary, it is desirable to test the operation of the relays and continuity of the pilot circuit at regular intervals, by manually operating the relays to open the switches at the ends of a protected line. The amount of fault current upon which the relays are to operate having been previously determined and adjustments made for such values, no further tests are required except those to determine the mechanical condition of the relays and switches, and the continuity of the pilot wires.

To those who may contemplate the use of the balance system of relay protection, too much cannot be said in emphasizing the necessity of using series transformers of ample capacity and exactly similar ratios.

Determination of actual transformer ratios should be ascertained by actual tests on each group of transformers to be balanced against each other in service. By this method errors in ratio under abnormal overloads may be determined in advance and corrections made to insure the proper operation of the protective apparatus under all conditions.

In English practise a series transformer with a single primary turn and an open magnetic circuit has proven most satisfactory in all respects. Transformers of this design may be more conveniently tested and adjusted for balance than any other type, although series transformers of both open and closed magnetic circuit types are in general use, and after adjustment render equally efficient service.

Transformers used for feeder protection must be constructed with ample insulation between secondary turns, for when operated with secondaries open circuited or bucking, potentials are created in the secondary circuits which are usually in excess of those for which standard series transformers ordinarily used in our practise are designed. These potentials often reach 600 to 700 volts in transformers used with the Merz-Price system for the protection of long high-tension feeders.

In order to illustrate the application of this system of protection to various situations, there follows a series of diagrams, Figs. 3 to 8, showing typical arrangements and connections of transformers, relays and pilot wires, as used in protecting certain apparatus.

Fig. 3 illustrates the application of "current balance protection" to generators—series transformers of proper capacity and ratio inserted in the generator circuit with their secondaries connected through pilot wires to relays arranged to control the opening of the main generator switch.

Any failure within the generator windings or connections to the buses, which affects the balance of current in the main and

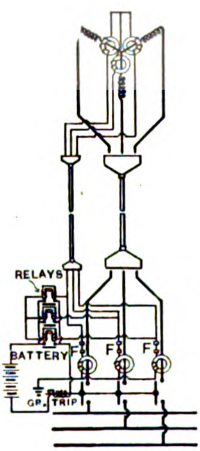


Fig. 3.—Generator Protection —Current Balance.

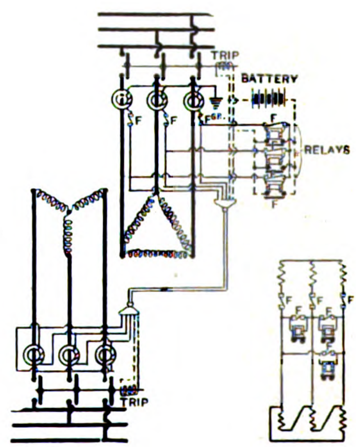


Fig. 4.—Transformer Protection —Current Balance.

secondary circuits, causes the relays to open the main switch and disconnect the generator from the system.

Fuses are inserted at *F* to shunt the relays when a time element feature is desired to prevent the main switch opening upon the development of heavy currents which sometimes occur during synchronizing.

In Fig. 4 is shown the arrangement of series transformers and relays for the protection of transformers. The small sketch shows the secondary circuits only. Fuses for the time limit protection marked *F* are included to provide for momentary rushes of magnetizing current, when the main transformer is connected to the system. It is customary to remove these fuses

after the transformer is in service if no time limit protection is then desired.

Fig. 5 shows a method of protecting against faults in feeders by the "e.m.f. balance method." This has been found more desirable than current balancing, as the energy required to overcome the resistance of the pilot wires on long feeders would be prohibitive. The two small sketches show methods of connection employed with grounded and non-grounded neutral systems.

Fig. 6 illustrates the application of "e.m.f. balance protection" to main feeders with tee connection on systems with insulated neutral. Tee connection on such feeders should be avoided wherever possible.

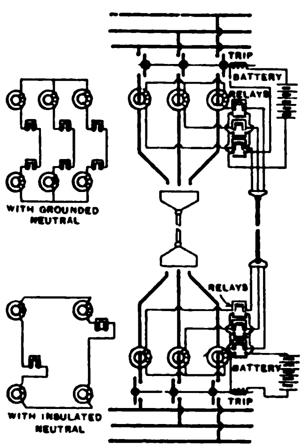


Fig. 5.—Feeder Protection—E. M. F. Balance.

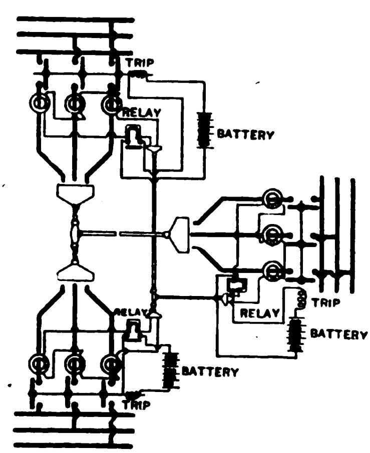


Fig. 6.—Feeder Protection—E. M. F. Balance.

Fig. 7 illustrates a method of protection occasionally used, styled "neutral wire balancing." The transformers are connected as for current balancing with the neutral wire connecting between the two points of equal potential at the ends of the protected section. In this case no current passes through the pilot system in which the relays are connected under normal conditions.

The method shown in Fig. 8 has its application to single radial feeders and depends for its operation upon the leakage of current to earth, from one of the conductors in a three-conductor feeder. Such unbalancing in the current in the three conductors of a feeder destroys the balance in the relay or trip circuit, and results in opening the main switch to disconnect the feeder.

As previously noted, the most reliable operation is secured where a storage battery is used to supply tripping current, although these batteries are not shown in some of the diagrams.

Referring for a moment to Fig. 1, there is shown the application of balanced protection to a high tension feeder system in which both ring and radial systems are combined. Two generating stations are shown feeding into the same net work, indicating the flexibility possible in the application of this form of protection to all situations. It will be noted that a combination of two methods is employed at the ends of the feeders at generating stations, and at points where cross connections between feeders are made at substations.

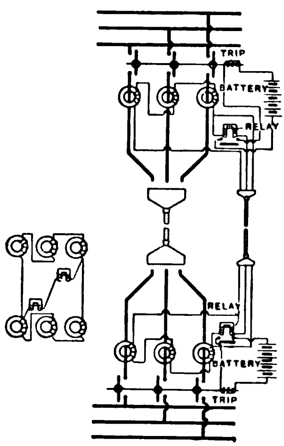


FIG. 7.—FEEDER PROTECTION—E.M.F. BALANCE—NEUTRAL WIRE METHOD.

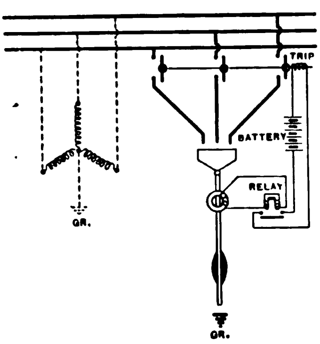


FIG. 8.—MERZ-PRICE CORE BALANCE OR LEAKAGE PROTECTION METHOD.

As the Merz-Price protection is for faults and not for overloads, it is advisable to add a time limit relay for overload protection at certain points as indicated, to provide for possible contingencies such as a bus bar fault or switch failure in a substation, which being simply a short circuit between the conductors of a feeder, would still result in a uniform current throughout the length of the feeder, and therefore not affect the balanced protection. This possibility is actually very remote, as ordinarily such a fault would naturally develop shorts to earth, producing conditions favorable for the operation of the balanced protective devices.

Time limit relays on cross connections between feeders serve

to separate the feeders into groups upon a short circuit occurring on any single feeder, thereby limiting the spread of trouble beyond the original feeder or group of feeders in which it occurred.

It is advisable to adjust time limit relays for practically instantaneous tripping when used on cross connections between feeders, and when employed at generating station ends of such feeders in conjunction with balance protection, relatively long time limit settings should be employed.

After personally observing the results attained by users of the Merz-Price system in England in protecting station apparatus, such as transformers, the writer deemed it desirable to apply this form of protection to the transforming apparatus in the sub-stations of the company with which he is connected.

Current balancing proved the most desirable system of protection to employ, affording as it did an opportunity to use existing series transformers for operating the relays. These transformers were tested carefully to determine their actual capacity and ratio under heavy overload conditions. The results show that certain types of standard transformers are entirely satisfactory for use with this system of balance protection. Experimental circuit closing relays were constructed and substituted for the time limit overload relays formerly used in the protection of three 5000-kw., three-phase, 7000/14000 volt, 60-cycle transformers in the main generating station of the Boston Edison Company. Several months' use of the apparatus has given most satisfactory results in handling the heavy rushes of magnetizing current developed by switching operations when the transformers are cut into service, as well as those caused by faults in overhead and underground feeders. The relay which was finally adopted is of the simplest form, comprising suitable circuit closing contacts and a single solenoid provided with two similar windings of the same number of ampere turns. One relay was provided for each phase of the main transformer to be protected, with its two windings so connected to the secondaries of series transformers that they opposed each other when the current in the main transformer windings was normal.

The relays, Fig. 9, were adjusted to close with an unbalanced current equivalent to 150 per cent of the normal load current of the transformer, this allowance covering the magnetizing currents developed when a transformer was switched into service, without making it necessary to resort to time limit attachments on the relay to meet these conditions.

Following this experimental installation, it is now proposed to similarly equip all transformer installations in substations throughout the system, using standard transformers now in service and substituting the special relay for the present equipment of inverse time limit relays.

The introduction of this system of protection will afford immunity from the interruptions of service sometimes caused by heavy short circuits on distributing circuits unnecessarily opening the main switches on substation transformers, through the action of instantaneous or time limit overload relays as now employed.

The use of this system of protection will be extended to all new transmission lines as installed, particularly those lines serving suburban districts. This course will finally introduce many protected sections of line into the system and materially aid in improving the present

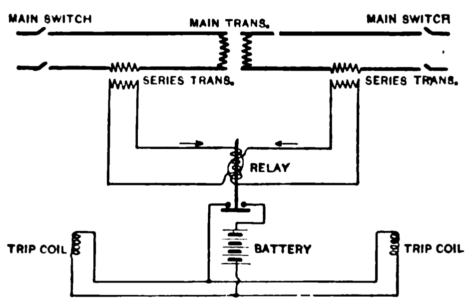


FIG. 9.—TRANSFORMER PROTECTION—EXPERIMENTAL APPLICATION OF CURRENT BALANCE METHOD.

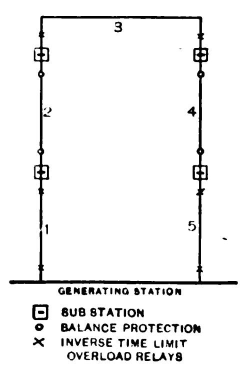


FIG. 10.—RING SYSTEM OF FEEDERS.
Sections 1, 3, 5, protected by I. T. L. overload relays.
Sections 2, 4, protected by Merz-Price system.

methods of relay protection. Where such protected lines are conveniently located the operation of closed ring systems will become feasible, for through the introduction of one or more such protected sections, improved selected action may be obtained from the relays now in use on existing lines which may go to make up a ring feeder.

The possibilities of improving conditions by applying the "balance system" of protection to a limited number of lines in an existing system, where the expense involved to equip all lines is prohibitive, is illustrated in Fig. 10, in which is shown a typical ring feeder supplying several substations.

Three sections of this feeder are equipped with standard in-

verse time limit overload relays and two sections with the "balance protection."

Assume that sections 2 to 4 are adjusted to trip on fault currents equivalent to 20 per cent of normal full line current. Adjust time limit overload relays on 1 to 5 for twice normal full line current in three seconds, and adjust similar relays on section 3 for half these values. It will then be possible for a fault to appear on 3 causing its relays to open without interrupting the service on the other sections of the ring.

Similarly either section 2 or 4 may prove defective and be cut out of service automatically by the "balance protection" without affecting the other sections, assuming in each case that the lines comprising the ring are of sufficient capacity to carry the whole load in either direction.

Should section 1 be damaged it is probable that the relays on section 1 to 3 would open on account of their relative adjustments, thus interrupting service from two substations for a time at least. The same conditions would apply to a fault on 5, and although somewhat unsatisfactory in the last two cases, the results are a great improvement over those obtained from the use of inverse time limit overload relays ordinarily used for such stations. Variations in the location of the section of lines equipped with balance protection will introduce new combinations of relay adjustments, but the conditions suggested in Fig. 10 will illustrate the possibilities and results obtainable by a partial application of the balance protection to an existing system of feeders.

Another arrangement of the Merz-Price system is shown in Fig. 11, representing the application of the "magnetic balance system" to the protection of certain important tie line feeders connecting two large generating stations of the Commonwealth Edison Company, of Chicago.

In this case the magnetic balance system was chosen as it afforded an opportunity to employ existing series transformers, by simply adding relays and a special balancing transformer with windings arranged as shown in the illustration. The adaptation of this apparatus to an existing switchboard panel is shown in Fig. 12, where the change from inverse time limit overload protection was made with scarcely any disturbance to existing switchboard arrangements. Experience with this installation is somewhat limited, but in so far as operated the results are satisfactory, and the engineers of the company are studying the further application of the system of protection to other parts of the system.

Another system of relay protection has been devised by Mr. Höchstädter of Cologne, Germany, which while somewhat different in principle, effects the same results in feeder protection as the Merz-Price system. In this system, when applied to a three-phase feeder, a copper ribbon is wound spirally around each main conductor of a three-conductor cable during the process of manufacture. These ribbons are insulated from the main

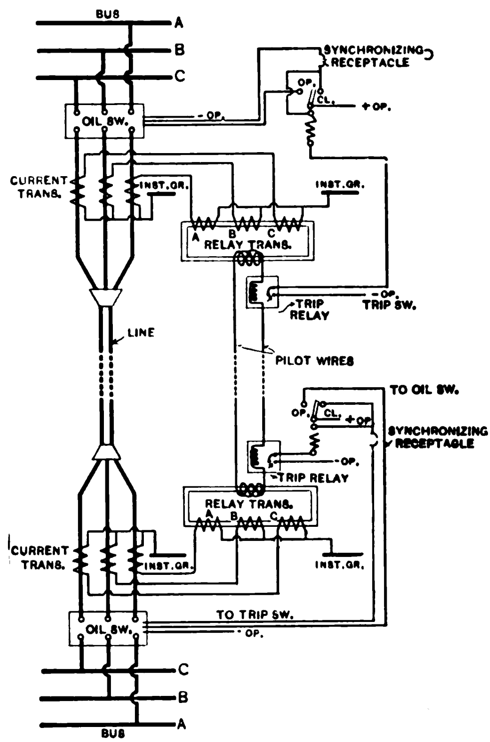


FIG. 11.—SPECIAL PROTECTIVE RELAY SYSTEM USED BY COMMONWEALTH EDISON COMPANY.

conductors and sheath, and from each other, and in service are connected to an auxiliary storage battery and suitable relays, all arranged to operate the main feeder switches upon the occasion of a fault in the main cable.

Whenever the insulation breaks down at any point in the cable, a connection is established between the main conductor and its copper ribbon, or between conductor, copper ribbon and sheath,

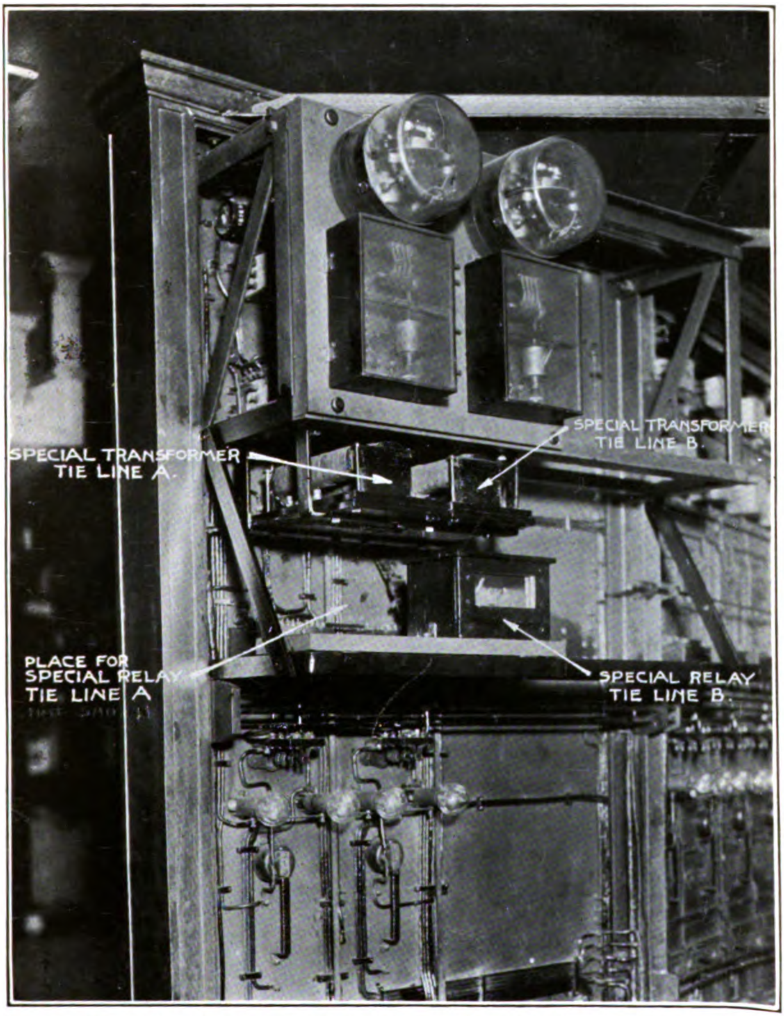


FIG. 12.—SPECIAL RELAY APPARATUS ON SWITCHBOARDS. [ELDEN]
COMMONWEALTH EDISON COMPANY.

thereby allowing current to flow in the relay circuit to actuate the feeder switches at both ends of the defective feeder, as clearly shown in a typical diagram of this system reproduced in Fig. 13.

Choke coils are included in the relay circuit to limit the alternating current which would otherwise flow in the circuit formed by the copper ribbons around the conductors.

This system admittedly possesses some admirable features, particularly in the absence of a separate pilot wire cable, and while somewhat complicating the construction of the main feeder cable by the introduction of the copper ribbons, this detail appears to have been satisfactorily accomplished.

A number of installations using the Höchstädter system of protection have been made in Germany, notably in Cologne, where an extensive three-phase ring transmission system at

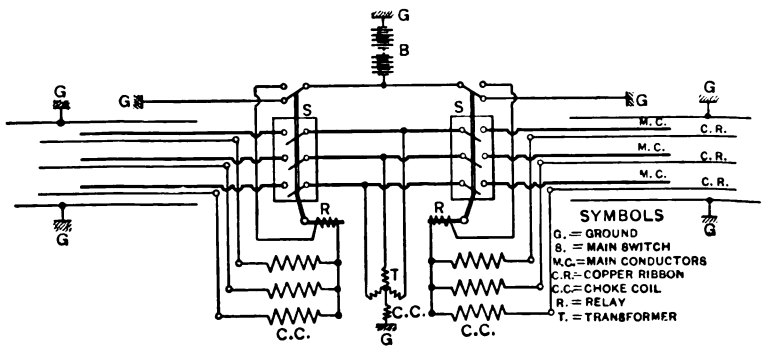


FIG. 13.—DIAGRAM OF CONNECTIONS OF HOCHSTADTER SYSTEM OF PROTECTION APPLIED TO A THREE-PHASE FEEDER.

25,000 volts has been in operation for a considerable period with great success.

While other modifications of the Merz-Price system have been developed and applied to commercial practise, there is always evident a desire in the minds of all engineers interested in the subject to do away with the pilot wires and accomplish the same results in other ways.

Messrs. Faye-Hansen and Harlow, of England, have brought out a system of balanced protection, in which the balancing of secondary currents from series transformers is accomplished by the insertion of variable artificial resistances in the secondary circuits, in a manner said to be more convenient than in the Merz-Price method. However, as the system is based on the principle of balanced protection and still requires pilot wires, although in

some cases less in number, there appears to be no decided advantage in using it in preference to the earlier method, unless it be that one prefers a scheme in which relays may be omitted and straight alternating-current trip coils employed to operate the main switches.

A method of protection for parallel feeders without pilot wires has been used by an English company, which consists of a combination of overload balanced relays at one end and simple trip coils at the other end of such feeders.

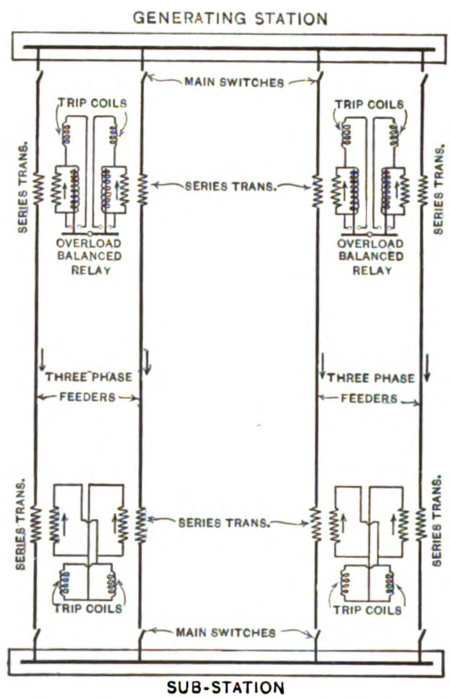


FIG. 14.—SELECTIVE RELAY SYSTEM WITHOUT PILOT WIRES.

Fig. 14 illustrates the method of applying this protection, from which it will be noted that if used with a single pair of feeders, both will be cut out should either feeder prove defective.

If, however, two pairs of feeders are in service the protection may be made selective, in so far as trouble on one feeder in a pair will only cause that pair to be cut out of service, leaving the station running from the remaining feeders without interruption. While this method has been used to some extent with success, it

is apparent that in principle it is not discriminative except under certain conditions, and, therefore, is not fully adapted to all conditions met with in practise.

There will be undoubtedly other methods of protection brought forward in the future to improve the operation and reliability of our electrical systems. In the meantime those engineers who have difficult problems of this character in hand may with profit investigate the improved methods employed in foreign countries in the protection of electrical equipment, with the assurance that a solution of practically all problems of that character may be found.

In closing the writer wishes to acknowledge the assistance rendered by Mr. Charles H. Merz and his assistant Mr. P. V. Hunter in furnishing information and diagrams concerning the construction and operation of their system.

I am also indebted to the engineers of the Commonwealth Edison Company for the information regarding their experiments with balance protective devices, all of which assistance has made possible the presentation of this paper.

A paper presented at the 29th *Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June* 28, 1912.

LOCALIZERS, SUPPRESSORS, AND EXPERIMENTS

Application of Localizers of Faulty Feeders and an Arcing Ground Suppressor to the System of the Public Service Electric Co., and Descriptions of Several Experimental Studies

BY E. E. F. CREIGHTON AND J. T. WHITTLESEY

The object of this paper is expressed briefly in the title. The localizer is a special type of relay which is connected to the current transformers of each feeder. When an accidental contact or arc occurs between one phase and ground on any feeder, the localizer of that feeder lights a signal lamp and sounds an alarm in the switchboard room.

The localizer is part of the general scheme of protection of cable systems. It is used especially in connection with the arcing ground suppressor.* The arcing ground suppressor extinguishes an accidental arc from one phase to ground in a small fraction of a second after it forms. The localizer indicates the feeder that is faulty. The switchboard attendant may leisurely substitute a spare feeder for the faulty one and clear the circuit of the fault without an interruption of service.

The Public Service Company of New Jersey covers the entire state. There are three systems, namely, the northern, middle and southern. The tests were made on the northern system. On this system are both overhead and underground transmissions. There are 47 miles of cable operating at 60 cycles, as much more at 25 cycles, and 32 miles of spare cable. There are 72 miles of open wiring on poles used exclusively on the 60-cycle system. The generated potential is 13,200 volts and the generators are directly connected to the lines. There are several

*See Proceedings, A. I. E. E., Feb., 1911.

power plants and two systems at different frequencies which are operated together at times through a frequency changer. All the tests herein described, however, were made at the Marion Station, using only one generator of 9000 kw. capacity.

Some idea of the extent of 60-cycle system may be gleamed from the value of the electrostatic grounding current. When a contact is made between one phase and ground the unbalanced condenser current rises to 60 amperes (measured). The momentary rush of current to ground is, naturally, many times greater.

The Remarkable Changes in Potentials by Grounding. When there is no ground on the system the potential from each phase to ground is the *Y* potential (7600 volts). This is shown in Fig. 1 by the lines 01, 02 and 03. When phase 2 is brought in direct contact with the ground its potential to ground is zero and the potentials of phase 1 and phase 3 to the ground is the delta potential, 13,200 volts. Without special consideration one is inclined to assume that when there is a medium value of resistance interposed between phase 2 and ground, the potentials to ground will be represented by some such intermediate values as phase 1, phase 2 and phase 3, Fig. 1. This, however, is far from true. This was first noticed from the behavior of the selective relay of the arcing ground suppressor. When one phase of a circuit was grounded through a relatively high resistance there was no movement of the corresponding arm of the selective relay, but the arm corresponding to one of the other phases moved toward its contact. Much to our dismay we found that this effect promised to put a limit on the maximum sensibility at which the selective relay could be set to operate.

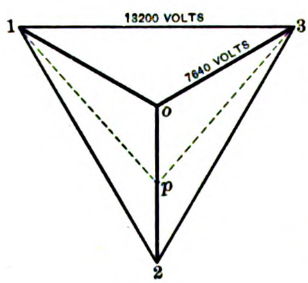


Fig. 1.

The actual potentials from each phase to ground are shown in Fig. 2 for all values of grounding current. These measurements were obtained by varying the resistance from phase 2 to ground by means of a water rheostat. A remarkable condition is shown. When the resistance is gradually decreased from an infinite value the potential of the grounded phase shows scarcely any change. But the potential of phase 3, which is not being grounded, shows a gradually diminishing value until the current reaches

16 to 20 amperes, then it gradually increases. Over the total range of grounding current, the potential of phase 1 to ground very consistently increased, but not along a straight line. Before a dead ground is reached the potential of phase 1 rises to a value actually greater than the delta potential of the circuit. When the resistance to ground reaches zero, phases 1 and 3 both assume the delta potential. In considering the potential of phase 3, attention is directed to the impossibility of setting the selective relay for a drop in potential of less than 19 per cent, as such a setting would cause the relay to close the wrong switch of the arcing ground suppressor. This condition of the relay applied to cable systems has no significance, nor importance. Faults

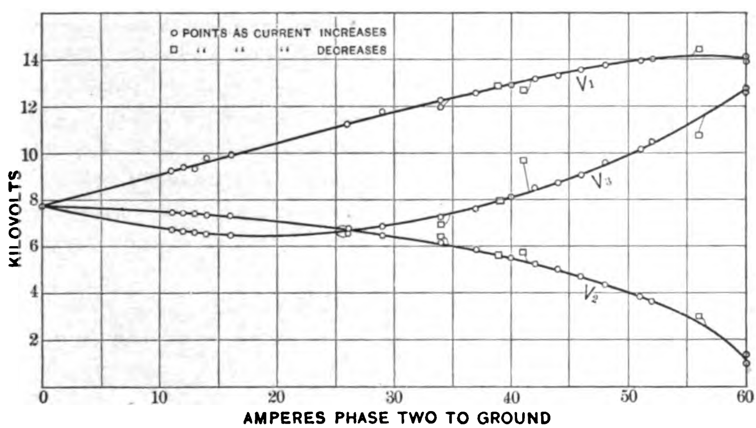


FIG. 2.—VARIATION IN VOLTAGE OF EACH PHASE TO GROUND AS CURRENT, PHASE 2 TO GROUND, VARIES.
Curves from test data, readings 27 to 49, Aug. 22, 1911.

in a cable develop immediately into a condition of low resistance. This matter of resistance of accidental grounds will be treated in more detail farther on in the paper.

The volt-ampere relation of the different phases relative to earth are shrouded in a mist of mystery when plotted in rectangular coordinates. This mist is immediately dissipated if the plot of the data of potentials is made on a triangle of the three phases. As a basis to justify this method we know from measurements that the generator continues to generate the same potential between phases independent of the presence or absence of an accidental ground. Since we are not treating of transient effects at present it must be understood that the foregoing statement is not intended to apply to the first instant that a ground

appears. Under normal conditions of load, then, the delta potentials are not materially disturbed by a ground on one phase. This means that the points 1, 2 and 3 of the triangle in Fig. 3 are fixed and the potential of each phase to ground may be plotted from its corner. Since the earth potential itself is the same for all three phases, the length of the lines from the three corners must meet in a point. Plotting the simultaneous potentials of the three phases gives a semi-circle on the *Y* potential as a diameter. For a particular condition of resistance to ground the point *p* is given. The potential from phase 1 to ground is represented by the length of the line 1 *p*. The direction of this line indicates its phase relation. Likewise the potential from phase 3 to ground is represented by the line 3 *p*. In the potential from phase 2 to ground, represented by the line 2 *p*, it is known that the current is in phase with the electromotive force. This potential is in the drop across the resistance situated between phase 2 and ground. By actual measurement it was found that during these tests the generator continued to generate the normal value of *Y* potential which is represented by the line 02. From fundamental considerations it is known that the *Y* potential 02 must be the vector sum of the resistance drop *p* 2 and the reactance drop *O p*.

Since there is no inductance in this circuit the angular displacement of the current, which is in phase with the line *P* 2, must be due to capacity in the circuit.

The question arises, which electrostatic capacity comes into play to cause this angular advance of the current? The capacity in question is evidently not the capacity of phase 2 to ground. Conditions are represented in a simplified form in Fig. 4. In this figure the capacities between the three conductors are not shown because the charging currents between conductors, except for transitory effects, remain practically constant whether a phase is grounded or not, since the potentials between the phases remain constant. In other words, an artificial separation of the different capacities is made for the sake of convenience. Returning to the consideration of phase 2, the resistance between this phase and gound is in parallel with its capacity to ground. After the first moment, the current which flows in the resistance comes directly from the generator and not from the condenser 2. The current which flows through the resistance to the sheath returns to the generator through the condensers 1 and 3. The potential *O p* in the diagram Fig. 3 is the vector potential drop across the condensers in series with the resistance.

The current then that flows through the resistance from phase 2 to ground returns not only by phases 1 and 3 of the grounded cable but also by the same phases of all the other cables through their electrostatic capacity to ground. In this way it is seen, from one view point, that current goes out from the generator on the phase of the grounded cable, to a value in this case of 60 amperes, and returns in a subdivided form by being distributed among all the cables. From another view point, a current flows out in one of the current transformers of the grounded cable which does not return through two adjacent transformers on the other phase of the same cable. This makes the sum of the currents in the three transformers not equal to zero. This unbalanced condition produces the current in the localizer relay which causes it to operate. It should be noted that the same condition holds only to a lesser extent in all the other cables which are not grounded.

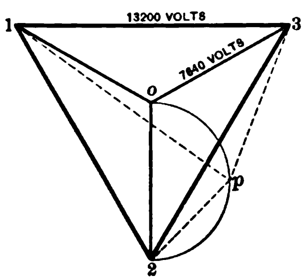


FIG. 3

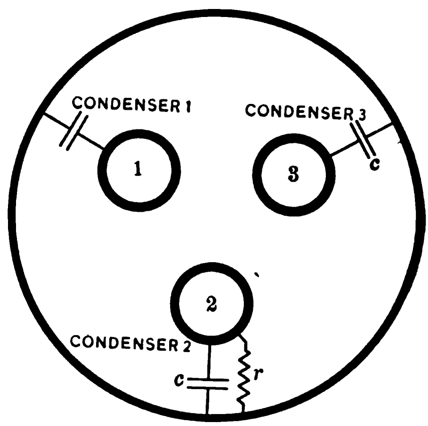


FIG. 4

The relations of the potentials to the current expressed in the rectangular coordinances of Fig. 2 are worked out mathematically from the diagram of Fig. 3 and are given in the summary of this paper. It may be evident to some engineers that this whole matter could have been worked out symbolically. The experimental method used with the interpretation of the data is much more trustworthy than the symbolical method, however, on account of the difficulties in obtaining by abstract analysis all the factors involved.

In Fig. 5 the conditions are shown for two values of resistance. When the resistance is very high then the potential from phase 2 to ground represented by $m\,2$ is nearly equal to the Y potential, and the current is nearly in phase with the Y potential. The potential $O\,m$ across the condenser at this time is very small.

If further proof were required that the condenser involved is not the capacity of phase 2 to ground, it is given by this diagram of Fig. 5 when the resistance to ground is high, as in the case assumed. Then the potential from phase 2 to ground, which is the potential on condenser 2, is practically the normal Y potential and not $O\ m$.

When the resistance to ground is low then the potential across the condenser is $O\ n$ and the potential across the resistance is $n\ 2$. Since the condenser effect now predominates, the current to ground is practically 90 deg. in advance of the Y potential 02. At this time the capacity current has reached practically its full value as the resistance is too small to affect it sensibly.

Comments on the Tests

These tests were made to investigate the applicability of the arcing ground suppressor to cable systems. It is of interest to note here that although the system was grounded more than 100 times by the arcing ground suppressor, no high potentials were caused. The condition of full ground was approached very gradually. During this time needle gaps were placed between phases and from each phase to ground. Note was taken also of discharges on the lightning arresters. On one day at a particular time the lightning arresters in two stations discharged during the grounded condition. Every effort was made to reproduce these effects but without success. The tests show that a contact ground on one phase of this system produces no abnormal potentials. The two non-grounded phases simply rise to delta potential above ground. The factor of safety in the insulation of the cables makes the application of delta potential harmless. During the periods of grounding, which sometimes were purposely carried to several minutes duration, there was no disturbances of the power on the system although there were synchronous machines in operation. During part of the time a two-phase system was connected to this three-phase system. This we believe would increase the possibility of surges, but no surge was noted.

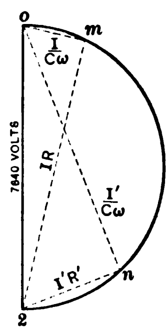


Fig. 5

In making and breaking the grounds on the circuit, it is well known from volumes of theory on the subject of transients, especially the classical work by Dr. Steinmetz, that oscillations

will take place. If no resistance had been used one might look for high potentials from these oscillations. It is well to note that in every case the grounds were made initially with some resistance in series. In a former paper before the Institute, on the arcing ground suppressor, the construction of the grounding switch is shown with a resistance in the oil pot. As the contact blade descends it first picks up this series resistance which is designed to damp out oscillations. An instant later after this ground takes place the resistance is cut out by a further movement of the blade which makes a direct contact between a phase and ground. In opening the switch the first movement of the blade throws the resistance in series again with the ground and when the contact to ground is finally broken it is done through the damping resistance in the oil pots. To this condition in the protective apparatus we can attribute the immunity

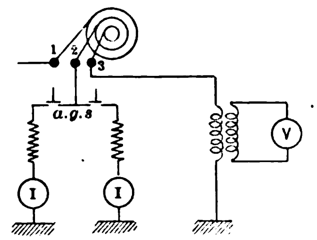


FIG. 7

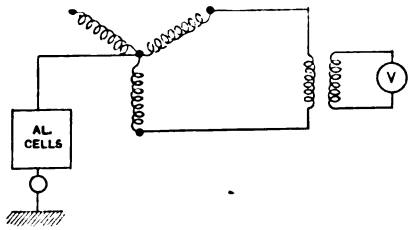


FIG. 9

from troubles such as occur from the usual accidental arcs to ground. The value of the use of the critical resistance in the oil pots was evident when the arcing ground suppressor switch was harmlessly made to pump open and shut rapidly for some time.

OSCILLOGRAPHIC STUDIES OF CURRENTS AND POTENTIALS WHEN THE SYSTEM IS GROUNDED SUCCESSIVELY THROUGH A RESISTANCE TO GROUND AND THE SWITCH OF THE ARCING GROUND SUPPRESSOR

In making these oscillographic tests, two instruments were used simultaneously. One instrument had its vibrators numbered 1, 2 and 3; the other, 4 and 5.

For the first oscillogram, *P.S.* 7, Fig. 6, the connections of the circuit for the vibrators 1, 2 and 3 are shown in Fig. 7.

The object of this test was to show the operation of the arcing ground suppressor. For vibrators 4 and 5 the connections are shown in Fig. 9, and the oscillogram in Fig. 8. One vibrator

measured delta potential and the other vibrator measured current to ground through an aluminum cell connected directly between the neutral of the generator and earth.

Fig. 6. *Oscillogram P.S.* 7, *Vibrators* 1, 2 *and* 3*a*. Phase 2 of generator No. 8 was grounded. Generator No. 8 was not connected to the power system when this test was made.

Upper Record: Vibrator 1.—Voltage of non-grounded phase to ground.

Middle Record: Vibrator 2.—Current to ground through a resistance of about 300 ohms. This current is the electrostatic capacity current of the generator.

Lower Record: Vibrator 3.—A circuit parallel to the one of the middle record from phase 2 to ground. This circuit was a single pole switch of the arcing ground suppressor.

In this preliminary test a resistance of about 300 ohms was also placed in series with the switch of the arcing ground suppressor.

NOTES: The exposure on the film starts at a point at the right of the film marked zero time. At this instant both switches between phase 2 and ground are open, and therefore, the vibrators 2 and 3 show zero current and vibrator 1 on phase 3 shows normal Y voltage to ground. (7,740 volts effective.)

The small lumps in this generator wave represent the 17th harmonic. The 17th harmonic corresponds to 18 teeth per pair of poles. After about 2.75 cycles from the time marked zero time the first grounding switch closes, connecting phase 2 to ground through about 300 ohms resistance. This is shown in the oscillogram by the disappearance of the zero line. Due to vibration of the contacts of the oil switch the record of vibrator 2 is initially so broken as not to be clear. It becomes clearer, however, in its continuation at the left end of the oscillogram.

When the first switch closes to ground the voltage of phase 3 as indicated on vibrator 1 immediately jumps to approximately delta potential. This takes place in spite of the 300 ohms in series to ground. The electrostatic capacity of the generator is so small that the resistance of 300 ohms has very little effect in limiting the grounding current from reaching its full value. Note has already been made of the high value of the 17th harmonic. This harmonic is greatly magnified by the capacity of the windings of the generator. In a later oscillogram it will be shown that when the generator is loaded by being connected to the system the effect of the teeth of the generator in producing the 17th harmonic disappears.

Coming now to a consideration of the arcing ground suppressor

switch as shown in vibrator 3—sixteen cycles (about $\frac{1}{4}$ second) after the first ground is put on the generator, the switch of the suppressor closes. The two circuits parallel to ground then divide the current between them.

Fig. 8. *Oscillogram P.S.* 7, *Vibrators* 4 *and* 5. The general conditions of the circuit have already been described.

Upper Record: Vibrator 4.—Delta potential.
Lower Record: Vibrator 5 is the current from the neutral of the generator through aluminum cells to ground. There is no visible current to ground shown until the first switch closes. The higher current initially on this record is due mostly to the charging current of aluminum cells. In a later oscillogram surges at the neutral will be shown in this circuit.

Fig. 10. *Oscillogram P.S.* 10, *Vibrators* 1, 2 *and* 3. The electrostatic capacity current to ground with a strong 17th harmonic is shown more clearly by choosing only a small part of the oscillogram. This test is a repetition of the previous one described. The film velocity is somewhat greater in order to bring out the form of the harmonics.

Upper Record: Vibrator 1 is the potential of phase 3 to ground.
Middle Record: Vibrator 2 is the electrostatic capacity current of the generator from phase 2 to ground.
Lower Record: Vibrator 3.—Zero line only is shown.

Fig. 11. *Oscillogram P.S.* 11, *Vibrator* 4 *and* 5. Grounding of generator No. 8 not loaded.

Upper Record: Vibrator 4.—The delta potential of the generator.
Lower Record: Vibrator 5.—The current from the neutral of the generator through the aluminum cells to ground.

NOTE: This oscillogram is reproduced especially on account of the initial surge that took place at the neutral the instant the generator was grounded.

Fig. 12. *Oscillogram P.S.* 19, *Vibrators* 1, 2 *and* 3. This record shows the opening of the grounding switch when the generator is connected to the whole system. There were about 500 ohms in series in the grounding circuit.

Upper Record: Vibrator 1 is the voltage of phase 3 to ground.
Middle Record: Vibrator 2 is the current from phase 2 to ground.
Lower Record: Vibrator 3 shows only a zero line.

NOTES: Only the last half cycle of the current to ground is shown on this oscillogram, vibrator 2. When the current ceases in vibrator 2, vibrator 1 shows a distortion of its zero line which is probably due to a magnetic effect in the potential trans-

former. It should be noted in the small part of the current wave that is visible that since all the cables were connected to the generator and the normal load was being taken, the 17th harmonic disappears, leaving the current wave smooth.

Fig. 13. *Oscillogram P.S.* 20, *Vibrators* 4 *and* 5. This test illustrates conditions while phase 2 is being grounded, first, through 25 ohms resistance, then, 16 cycles later, through the arcing ground suppressor switch which in its final closed condition had no series resistance.

Upper Record: Vibrator 4 was again the delta potential.
Lower Record: Vibrator 5.—The current from the neutral of the generator through aluminum cells to ground.

NOTES: The only subject worthy of note in the wave of delta potential is the absence of harmonics. In the current from the neutral to ground, (the lower record) the initial current rush is shown of comparatively small magnitude. After about 16 cycles the switch of the arcing ground suppressor closes and cuts out all the resistance in phase 2 to ground. Under this condition there is an unusual and remarkable although harmless surge of potential at the neutral which makes itself evident by considerable current from the neutral to ground. This surge first increases, then decreases slightly, and then increases again, and decreases to zero. The cause of this surge was not found, and it could not be reproduced. Although many tests were made it appeared but one other time. It may have been due to an unbalanced condition which occurred only when the ground connection was made at a certain unknown point in the cycle of the generator wave.

Fig. 14. *Oscillogram P.S.* 34, *Vibrators* 1, 2 *and* 3.—This record demonstrates the operation of the arcing ground suppressor under normal running conditions of the loaded system.

Upper Record: Vibrator 1 is the potential of phase 1 to ground.
Middle Record: Vibrator 2 is the current from phase 2 to ground, through a contact intentionally placed on the circuit to start the operation of the arcing ground suppressor.
Lower Record: Vibrator 3.—Current through the switch of the suppressor from phase 2 to ground.

NOTES: The potential of phase 1 to ground is shown initially at the middle of the film, where the record starts, at its normal value of 7600 volts. After about five cycles, the intentional ground was placed on the circuit. This shifts the neutral and

causes the potential of vibrator 1 to rise somewhat (9150 volts). Sixteen cycles later the arcing ground suppressor switch closes on its first contact and raises the potential from 9150 volts to 11,750 volts. Four cycles later when the suppressor switch is entirely closed the potential of phase 1 rises to the delta value, namely, 13,150 volts effective.

Following through the conditions of vibrator 2, the intentional ground to start the operation of the suppressor occurred about five cycles after the shutter of the oscillograph opened. There was a small resistance in series in this circuit from phase 2 to ground, which limited the grounding current to 42.5 amperes. After a duration of about 16 cycles the arcing ground suppressor switch partially closes and reduces the grounding current in vibrator 2 to 20.4 amperes, and when the suppressor switch closes entirely four cycles later it shunts out the current from this intentional ground which takes the place of the accidental ground in the operation of the device.

Tracing now the zero recorded in vibrator 3, the suppressor switch contact touches the resistance one-fourth of a second after the first ground was put on the system—34.2 amperes flows through this resistance. The wave is perfectly smooth. The switch blade requires four cycles to pass through the resistance contact to its home contact. When this resistance is shunted out there is a slight momentary oscillation of grounding current of a frequency of about 480 cycles per second which quickly dies out. During this test there was a discharge of the lightning arresters at Garfield substation and also at City Dock station. Note is made of this because of the impossibility of getting sufficient potential at any other time to cause a discharge of the lightning arresters.

Study of Phase Relation of Three-Phase Potentials when One Phase is Grounded Through More or Less Resistance

Fig. 15. *Oscillogram P.S.* 42, *Vibrators* 1, 2, 3, 4 *and* 5. Oscillograms were taken with different values of resistance from phase 2 to ground. From these oscillograms are chosen the following:

Oscillogram	Resistance to ground	Current to ground
P.S. 42	Infinite	Zero
" " 50	835 ohms	9 amperes
" " 51	180 "	34 "
" " 46	21.6 "	60 "

The system was operating under normal conditions of day load.

Upper Record: Vibrator 1 is the potential of phase 3 to ground.
Middle Record: Vibrator 2 is the potential of phase 2 to ground.
Lower Record: Is the potential of phase 1 to ground.

NOTE: It just happened in this oscillogram that the separation of the zero lines from each other corresponded to the difference in calibration of the vibrators and this brought the tops of the peaks of the three phases about on a line. This is only incidental but it may cause some confusion in reading the oscillogram. This oscillogram shows the natural condition of the waves when there is no ground on the system.

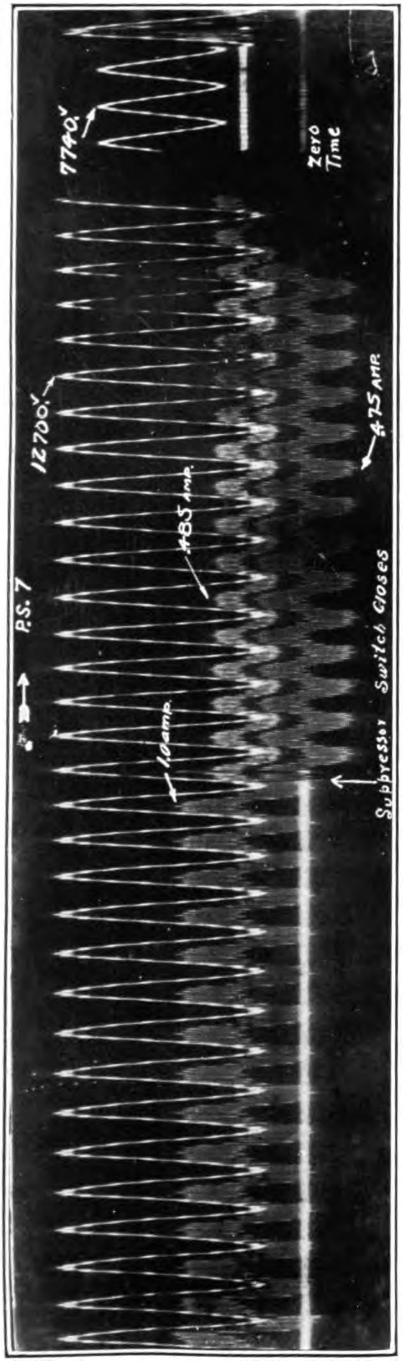
Vibrator 4 shows the delta potential of 13,200 volts. Vibrator 5 shows the potential of the neutral to ground. This neutral potential shows the presence of a 3rd harmonic which has an effective value of 660 volts.

Fig. 16. *Oscillogram P.S.* 50. In this case the resistance from phase 2 to ground is 835 ohms, which limits the current to ground to 9 amperes. The voltage of phase 2 to ground is 7500 volts while the potential of phase 3 to ground is only 6730 volts. This illustrates the condition already described of the reduction of the potential of phase 3 to ground when phase 2 is grounded through a comparatively high resistance. There is not yet sufficient shifting of the phase relation of the potentials of each phase to ground to be noted in this oscillogram.

Vibrator 5 shows an interesting development of the superposition of the third harmonic on the fundamental generator wave which appears as the neutral is displaced by the condition of ground.

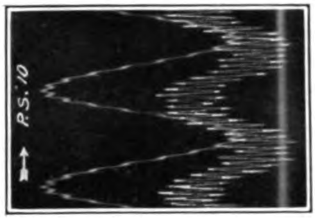
Fig. 17. *Oscillogram P.S.* 51. The resistance to ground has now been reduced to 180 ohms and the current from phase 2 to ground has risen, correspondingly, to 34 amperes. It will be noted also in vibrators 1, 2 and 3 that the potential of phase 2 ground has decreased to 6,120 volts, and the potential of phase 3 to ground has increased to 7,220 volts, while the potential of phase 1 has already increased to the relatively high value of 12,200 volts.

Fig. 18. *Oscillogram P.S.* 46. Resistance to ground is 21.6 ohms. The current from phase 2 to ground has reached practically its full value of 60 amperes. The potential of phase 2 to ground has decreased to 1295 volts. The potential of phase 3 has increased to 12,600 volts, and the potential of phase 1 to



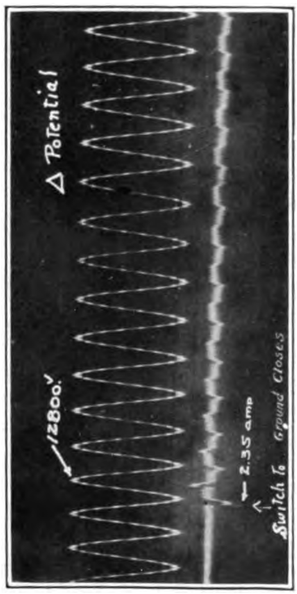
[CREIGHTON AND WHITTLESEY]

FIG. 6.



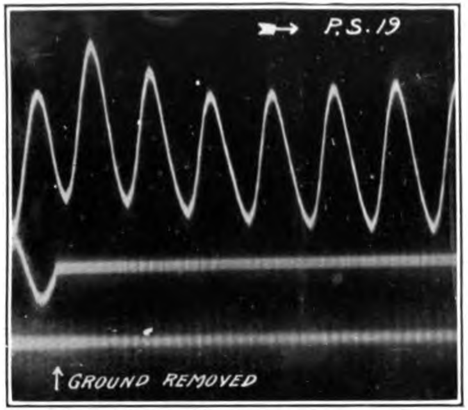
[CREIGHTON AND WHITTLESEY]

FIG. 10.



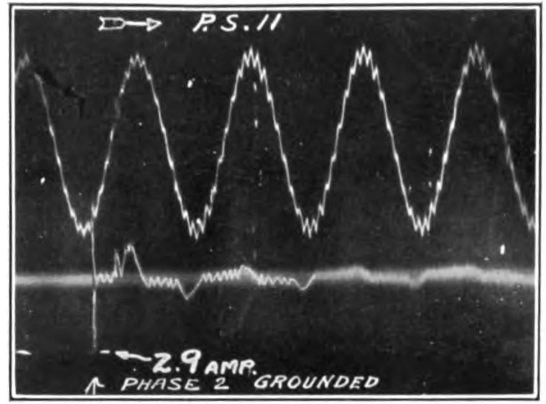
[CREIGHTON AND WHITTLESEY

FIG. 8.



[CREIGHTON AND WHITTLESEY]

FIG. 12.



[CREIGHTON AND WHITTLESEY]

FIG. 11.

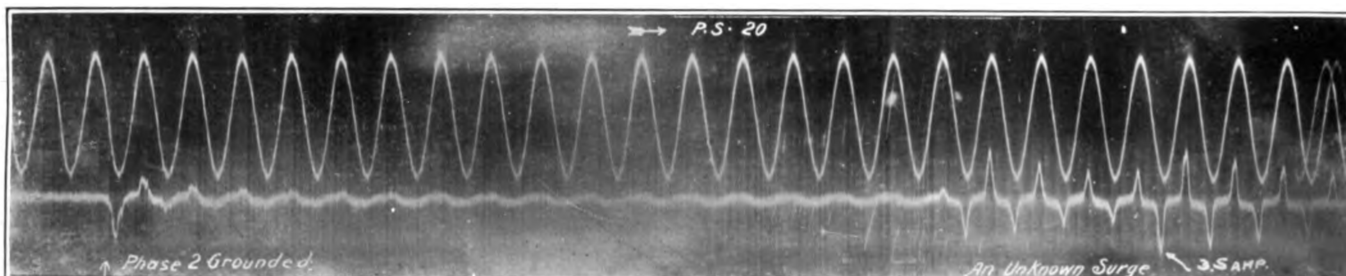


FIG. 13.

[CREIGHTON AND WHITTLESEY]

[CREIGHTON AND WHITTLESEY]

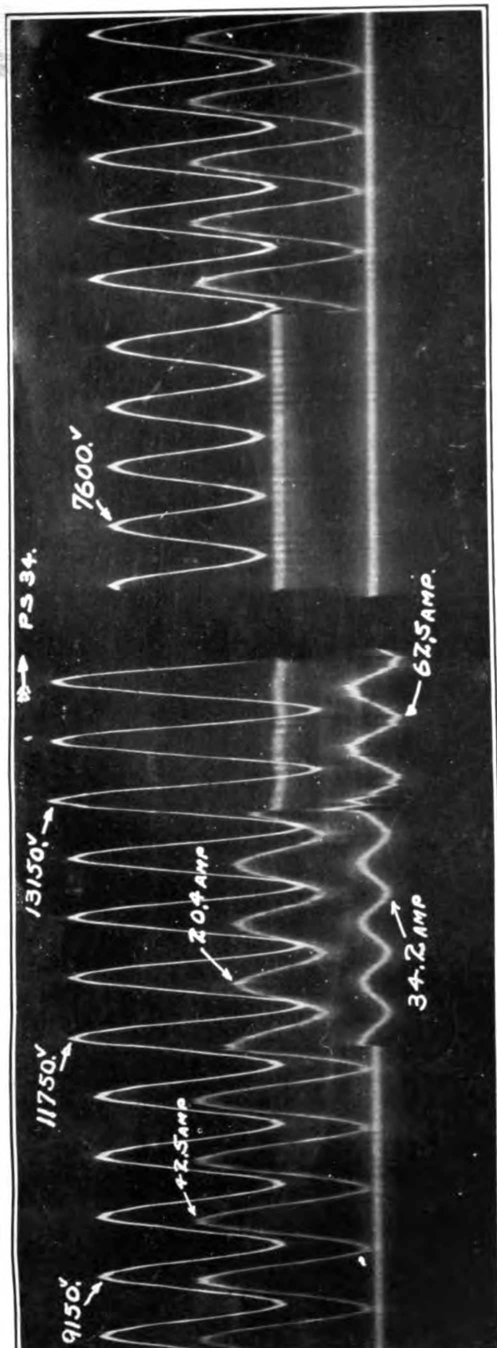


FIG. 14.

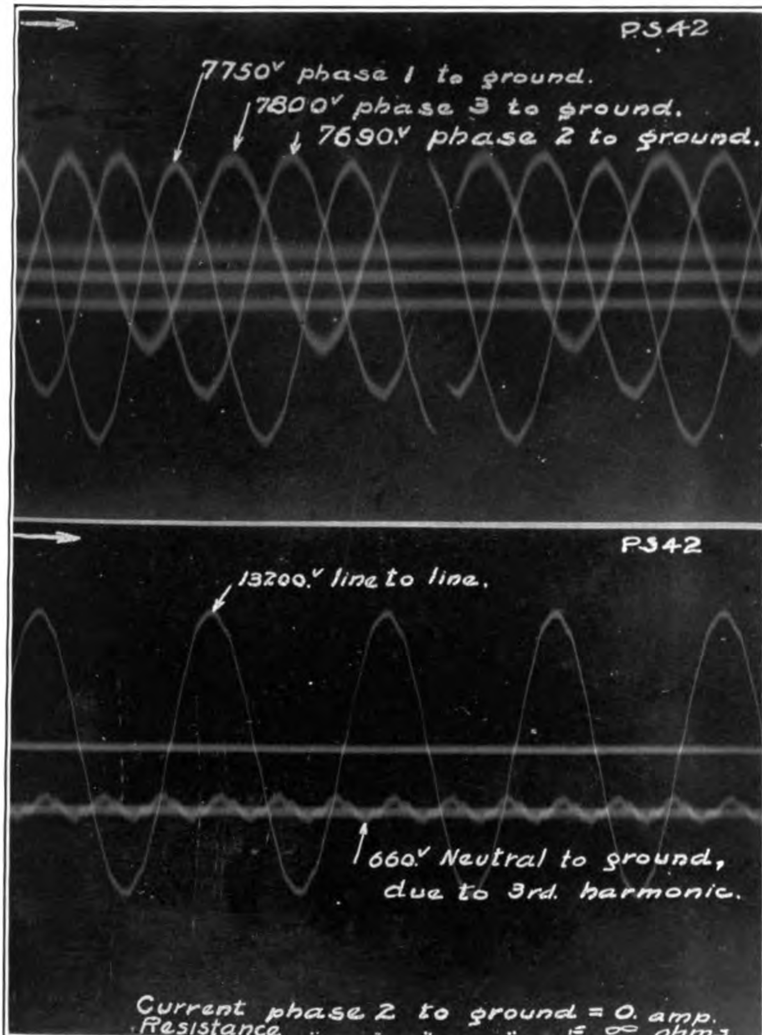


FIG. 15. [CREIGHTON AND WHITTLESEY]

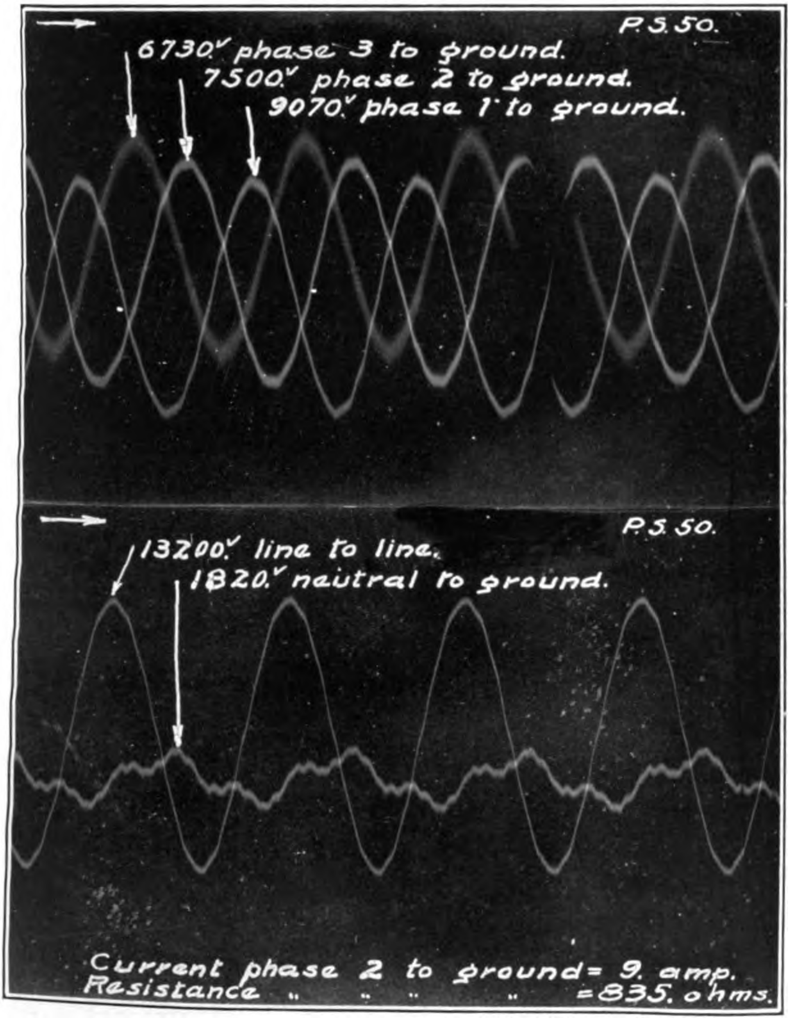


FIG. 16. [CREIGHTON AND WHITTLESEY]

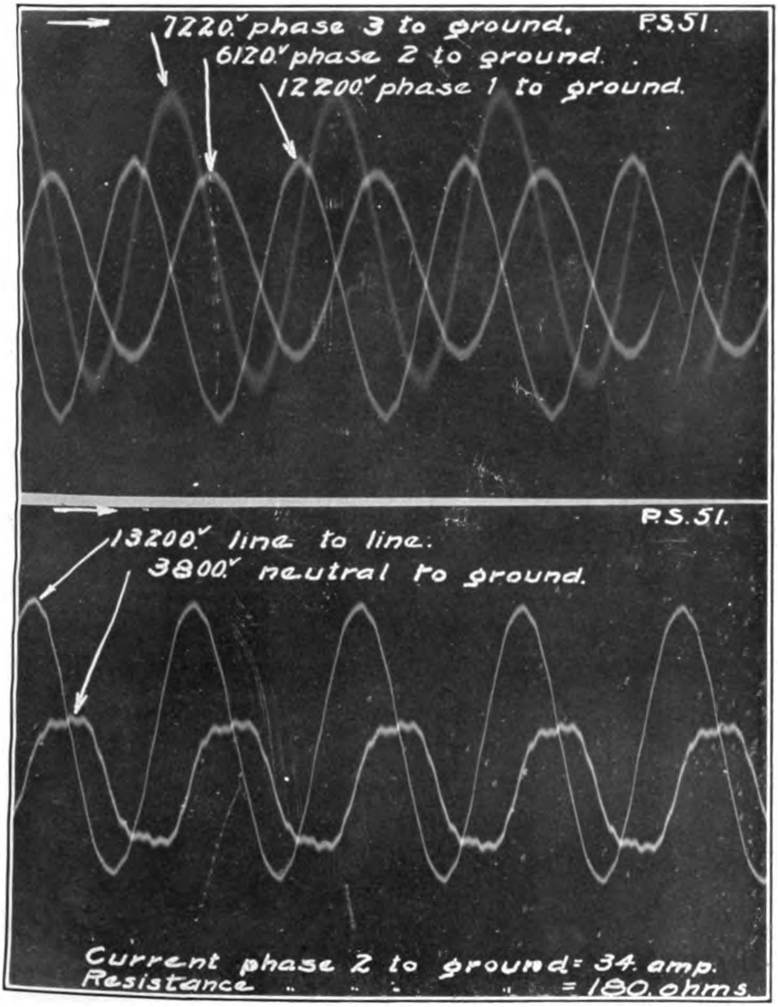


FIG. 17. [CREIGHTON AND WHITTLESEY]

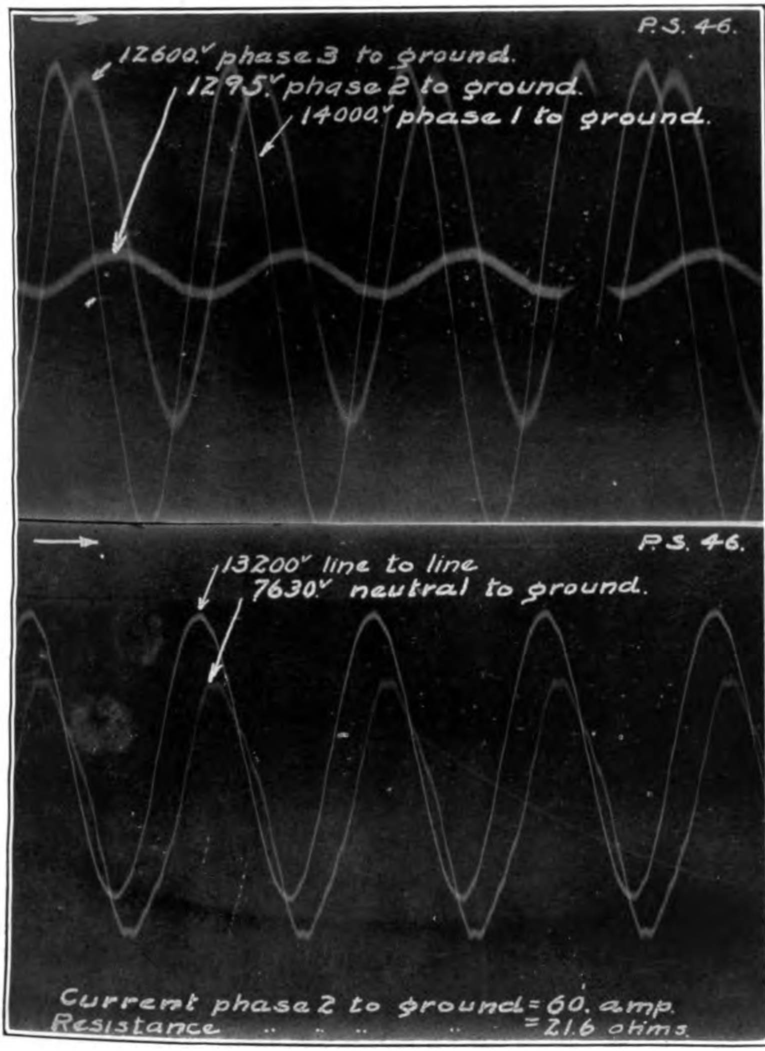


FIG. 18. [CREIGHTON AND WHITTLESEY]

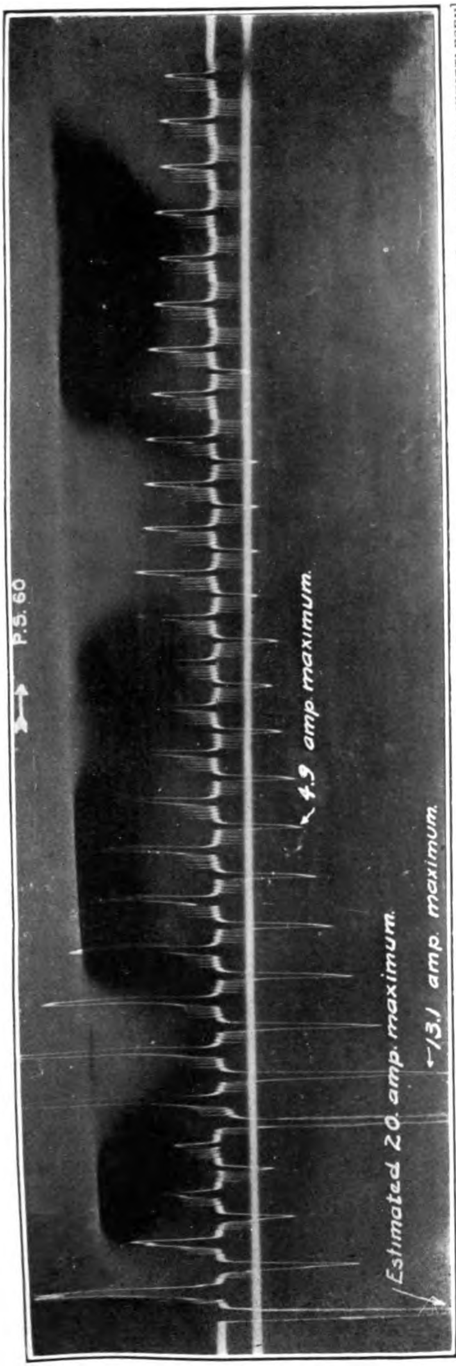


Fig. 19.

[Creighton and Whittlesey]

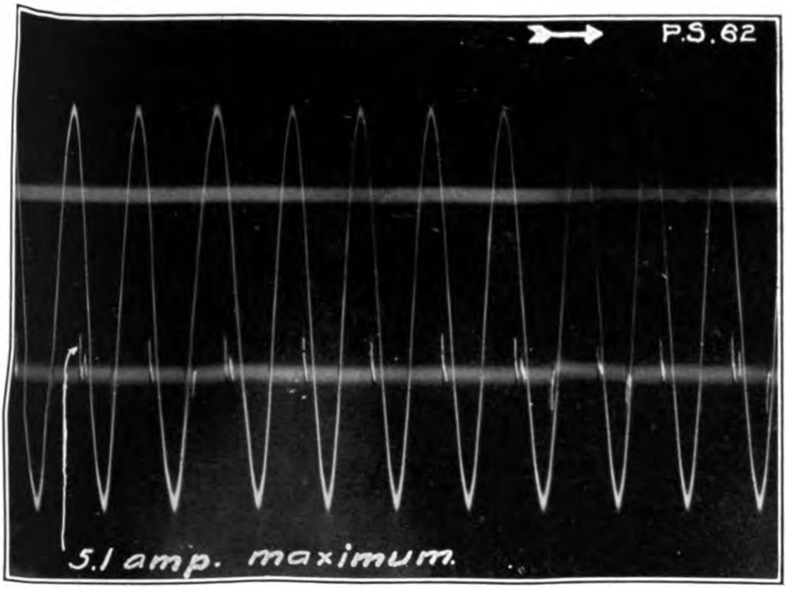


FIG. 20. CREIGHTON AND WHITTLESEY]

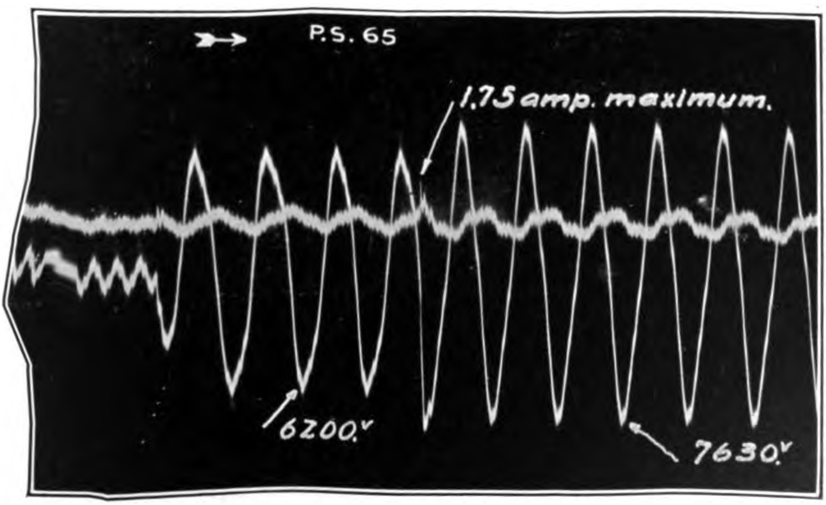


FIG. 21. [CREIGHTON AND WHITTLESEY]

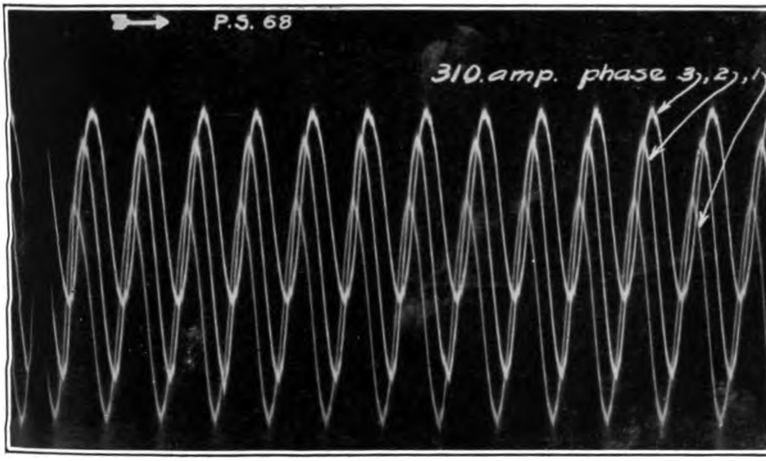


FIG. 22. [CREIGHTON AND WHITTLESEY]

FIG. 23. [CREIGHTON AND WHITTLESEY]

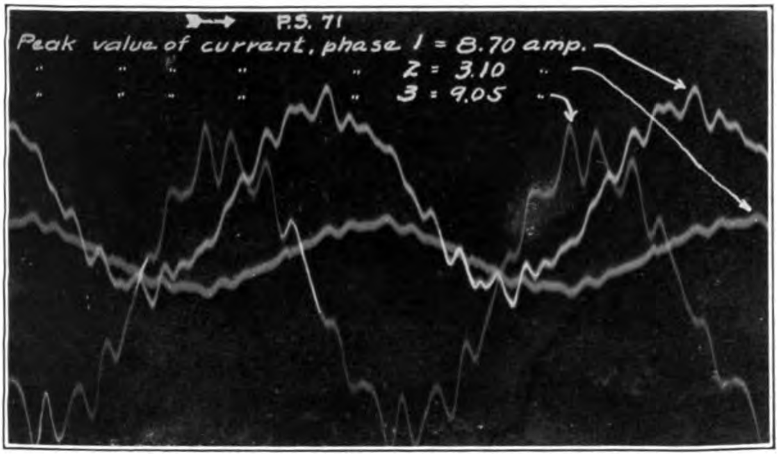


FIG. 24. CREIGHTON AND WHITTLESEY]

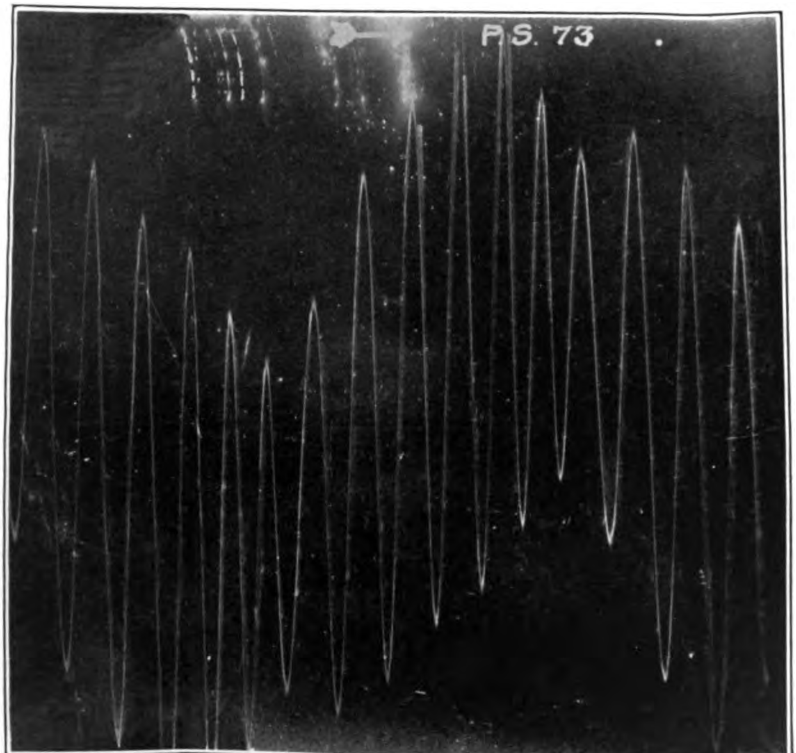


FIG. 25. [CREIGHTON AND WHITTLESEY]

ground has increased to 14,000 volts, which is greater than the delta value. The potential from neutral to ground shown on vibrator 5 has increased to 7,630 volts and the effect of the third harmonic shows relatively little in this large wave.

Fig. 19. *Oscillogram P.S.* 60, *Vibrators* 4 *and* 5. The entire 60-cycle system through the suppressor switch on phase 2 is grounded.

Upper Record:	Current from the generator neutral to ground through aluminum cells and a small gap.
Lower Record:	Zero line only.

NOTES: On the upper record, the shutter of the oscillograph opens at the extreme left. There is a period of zero current until the suppressor switch strikes the resistance contact in the switch pot. At this instant the current from the neutral to ground through the aluminum arrester is so great that it carries the deflection off the width of the film. By continuing the traces of the oscillogram until the lines meet an approximate value of 20 amperes is given. After the fourth cycle the resistance to ground in the switch pot is cut out by a movement of the blade of the suppressor switch. The surge of current at the neutral again goes off the film. The maximum value of current gradually decreases as the electric system becomes adjusted to the new condition of ground. It may be noticed that all the way through this record there are three to five small current surges before the large one takes place in each half cycle. This surge is due to the small gap that was placed in series with the aluminum cells in this test. This gap was placed there simply to determine its effect on the current to ground. The large deflections, however, are not due to this small series gap. The subsequent oscillograms were taken under the same conditions, but this condition could not be reproduced. It may be noted that this surge is similar to the one previously noted in Fig. 13. It is included in this paper with the idea of showing everything unusual and abnormal.

Fig. 20. *Oscillogram P.S.* 62, *Vibrators* 1, 2 *and* 3.

Upper Record:	Vibrator 2 shows a zero line, as it was not used.
Middle Record:	Vibrator 1 is the voltage from phase 1 to ground.
Lower Record:	Vibrator 3 is the current in the lightning arrester.

NOTES: This oscillogram was taken especially to record a discharge of an aluminum lightning arrester in a station. Since there was insufficient potential from the surges to cause a discharge over the horn gaps at their minimum setting, the gaps

were shortened sufficiently to spark at delta potential. The effective current in the arrester was 3.3 amperes by ammeter measurement. The peak of the instantaneous value given by the oscillograph showed about 5 amperes maximum.

Fig. 21. *Oscillogram P.S.* 65, *Vibrators* 4 *and* 5. During this exposure of the film, phase 2 of the entire system was grounded through the suppressor switch. During this time the lightning arrester had its gap so that it discharged but this discharge has no effect on either of the records of the vibrators shown.

Upper Record:	Vibrator 4 is the current from the generator neutral through aluminum cells to ground. The cells were directly connected without the intervention of a gap, such as existed in the previous figure.
Lower Record:	Vibrator 5 is the voltage from generator neutral to ground.

NOTES: At the left end of the record the third harmonic is prominent in both the current and potential wave, but naturally more prominent in the latter. When the suppressor switch closes the third harmonic becomes of relatively little importance. While the resistance in the switch pot is in series to ground the voltage of the neutral rises only to 6,200 volts, but after about four cycles this resistance is cut out and the voltage rises to 7,630 volts. At the instant complete ground takes place the aluminum cells at the neutral show a surge current of 1.75 amperes maximum.

Fig. 22. *Oscillogram P.S.* 68, *Vibrators* 1, 2 *and* 3. This oscillogram gives a record of the main load currents in the three phases during the period of grounding.

NOTES: The ground takes place at about the tenth cycle of the generator after the opening of the shutter of the oscillograph. There is no visible disturbance of the load currents resulting from grounding. This result was checked in a subsequent test. The absence of disturbances is explained by the fact that the 60 amperes of grounding current is nearly at right angles to the greater value of power current. The power current at this time was about 310 amperes per phase, at 87 per cent power factor. The total load was 6,200 kw.

Fig. 23. *Oscillogram P.S.* 70, *Vibrators* 1, 2 *and* 3. Charging current in the three phases of an unloaded cable which is not grounded. Energy was taken from generator No. 8 the same as in the previous test. The length of cable was 6.5 miles. The size of the copper conductor in the cable was No. 1 and the insulation was paper, 7/32 in. thick.

Notes: It is interesting to compare the wave form in this oscillogram with that shown in several others. For example, if it is compared to the one shown in Fig. 10, it will be seen that a different harmonic is magnified. In the present figure the most prominent harmonic is the eleventh, whereas in Fig. 10, oscillogram 10, the most prominent harmonic is the seventeenth. In regard to the oscillogram 10, it is necessary to explain that a cable only 3.5 miles long was connected to the generator at that time, but it had the effect of magnifying the seventeenth harmonic. In this case, Fig. 23, an idle cable 6.5 miles long was connected. It is somewhat confusing to find the eleventh harmonic magnified. This is explained by the fact that when the seventeenth harmonic was prominent the generator was without load, whereas when the eleventh harmonic was magnified the generator was carrying the normal day load of the system. Other comparisons will be made in the notes of subsequent oscillograms.

Fig. 24. *Oscillogram P.S.* 71, *Vibrators* 1, 2 *and* 3. Charging current in three phases of an unloaded cable, the same as in the previous test except that phase 2 is grounded at the bus bar. The generator is still carrying its normal load.

Notes: The effect of grounding phase 2 is to steal away some of the capacity current in the wire and divert it to the cable sheath. Phases 1 and 3 show an increase in capacity current of perhaps 40 per cent. The capacity current in phase 2 drops off about half. Special attention is directed to these variations and capacity currents during ground. The variations indicate a change in capacity. In another paper on a localizer it is endeavored to prove that this capacity current in the grounded phase does not affect the localizers in the non-grounded cables.

Fig. 25. *P.S.* 73, *Vibrator* 1. Charging current to ground in the same unloaded cable, 6.5 miles long (cable *H*). The potential is taken, however, from generator No. 4 which is not carrying any power.

Notes: In this record the thirteenth harmonic is more prominent even than the fundamental wave at 60 cycles. One might even consider the frequency from this generator in the cable as 780 cycles per second instead of 60. This record should be compared with previous records where the seventeenth and eleventh harmonics were prominent. Since there was no load in the generator the 12 teeth per pair of poles in the generator gave

their distorting effect undiminished by any armature reaction from load current. The effective current to ground was 19.1 amperes. The thirteenth harmonic is free of any visible higher harmonics. In comparing this oscillogram with that of the generator No. 8 shown in Figs. 6 and 10, the difference in design of the generator armatures explains the difference in wave form. In the case where the eleventh harmonic was prominent the explanation is probably found in attributing the eleventh harmonic to a generator in the City Dock power station.

It is evident these harmonics exist in more or less magnified forms under different conditions of operation. The possibility of resonance with these harmonics is very remote. The possible chance of occurrence is about the same as that of winning a prize in a Chinese lottery. Still, the possibility must always be kept in mind, and whenever occasional troubles occur of unusually damaging effects, no doubt the magnification of the harmonics by resonance may at times come in for part of the blame. It has often been noticed, for example, on a system, that arcing grounds will take place many times without causing any trouble, but finally one single arcing ground will cause widespread damage. These oscillograms are reproduced especially to point out the *possible* source of high potentials from resonance.

Measure of Capacity Currents Made on Three-Phase Transmission Cables when One Phase is Grounded, and Generator not Loaded. A number of tests were made of the distribution of capacity currents between the cables and sheath under conditions of construction. It was found that these currents deviated in value from the empirical laws that are given to cover such conditions. Not having time to look up the literature on this matter and fearing that the subject has been thoroughly covered, space is economized by not including them in this report. The fact that the currents do not check with the standard equations is easily explained by the change in the harmonics that have been illustrated in the preceding oscillograms.

In introducing this subject the object is simply to call attention to the fact that the usual equations given for capacity between wires and sheath have little practical value in determining the charging current from any generator to a cable.

Data of a Grounding Test. Readings, Nos. 27 *to* 50. Returning to the subject of accidental grounds the following table of a complete test is given for reference:

Reading No.	Hour	Potential to ground			I_2 to ground	R to ground	I localizer	Oscillo-gram
		V_1	V_2	*V.*				
27	3.24	7,740	7,720	7,800	0	00	0	
28	3.25½	9,250	7,500	6,700	11	682	0.3 ?	47
29	3.26½	9,400	7,450	6,620	12	621	0.35?	
30	3.27	9,370	7,440	6,600	13	572*	0.35?	
31		9,720	7,380	6,500	14	527	0.35	
32	3.27½	9,930	7,360	6,480	16	461	0.35	
33		11,250	6,780	6,600	26	261	0.48	
34		11,730	6,490	6,900	29	224	0.52	
35		12,250	6,180	7,260	34	182	0.60	
36	3.29	12,550	5,880	7,680	37	159	0.64	
37		12,930	5,520	8,050	40	138	0.70	
38		13,180	5,260	8,520	42	125	0.74	
39	3.30	13,310	5,040	8,760	44	114.5	0.76	48
40		13,530	4,780	9,180	46	104	0.80	
41	3.31	13,770	4,320	9,660	48	93.7	0.86	
42		13,910	3,900	10,150	51	76.5	0.88	
43		14,000	3,700	10,500	52	71.2	0.90	
44	3.33½	14,090	1,140	12,720	60	19	1.2	
45	3.34½	13,930	1,105	12,650	60	18.4	1.2	49
46		14,300	2,990	10,690	56	53.4	1	
47		12,600	5,760	7,680	41	140.5	0.70	
48		12,840	5,580	7,980	39	143	0.70	
49	3.36	11,950	6,360	6,960	34	187	0.56	

Relation of Kilovolts to Grounding Resistance in a Grounded Phase

In the previous illustration the relation between current and voltage for the three phases was given. In some cases it is valuable to know the relation between the voltages and resistance between a phase to ground. This is given in Fig. 26.

Relation of Power Lost in the Ground Circuit and the Current to Ground. For several reasons the energy lost in the grounded circuit is of value, also the conditions at which maximum energy loss occurs. It is evident that when the resistance is infinite there is no loss of energy, and again when the resistance is zero there is no loss of energy. The maximum loss occurs when the current is about ¾ its full value to ground. The relation at every instant is shown in Fig. 27.

Relation of the Power Lost in the Grounded Circuit, and the Difference of Potential Between the Grounded Phase and Earth. This relation is shown in Fig. 28.

Rate of Development of an Accidental Ground. When this work was first begun it was hoped that some device might be constructed which would indicate the early stages of the develop-

ment of an accidental ground so that the arcing-ground suppressor could be used to prevent an actual arc to ground by closing on the fault during this early stage. A brief consideration of the power curves already given will show the difficulties involved. For example, in Fig. 28 when the potential of the grounded phase is diminished by only 10 per cent the energy lost is 170 kw. From the standpoint of potential, it is not easy to make a device sensitive to a change of only 10 per cent and still maintain a high degree of reliability. From the standpoint of rapidity of development of the fault, it is quite evident that 170 kw. applied to a small hole in the insulation about one-half inch long will carry the resistance immediately down to a negligible value. Taking

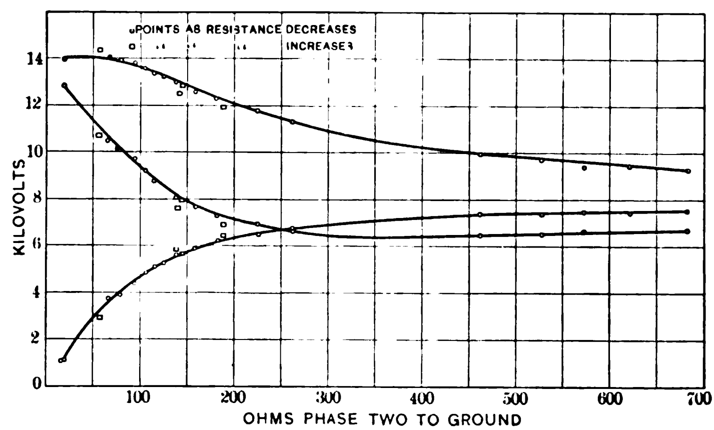


FIG. 26.—VARIATION IN VOLTAGE OF EACH PHASE TO GROUND AS RESISTANCE, PHASE 2 TO GROUND, VARIES.
Curves from test data, readings Nos. 27 to 49, Aug. 22, 1911.

another example in which the drop in potential is less, the conditions still seem to be hopeless. When the drop of potential to ground is only 1 per cent there is a loss of 70 kw. at the fault. Seventy kilowatts concentrated in a small fault is sufficient to develop it with enormous rapidity. In order to get the loss at the fault down to a value that will develop at such a rate as to permit the operation of a safety device, let us assume that the energy loss in an incandescent lamp is the upper value that can be allowed in the fault. When one considers that an incandescent lamp has a filament longer than the fault in the insulation, and that that filament becomes incandescent with 50 watts in it, we have surely not chosen, as a basis, a value of energy loss that

is too small. Still, when we consider this energy loss, the problem is far more difficult. A loss of 50 watts in the fault corresponds to a resistance of 1,000,000 ohms. When it comes to locating a fault of 1,000,000 ohms in a system where the insulation resistance runs from 2,000 ohms up to 500 megohms, the diffi-

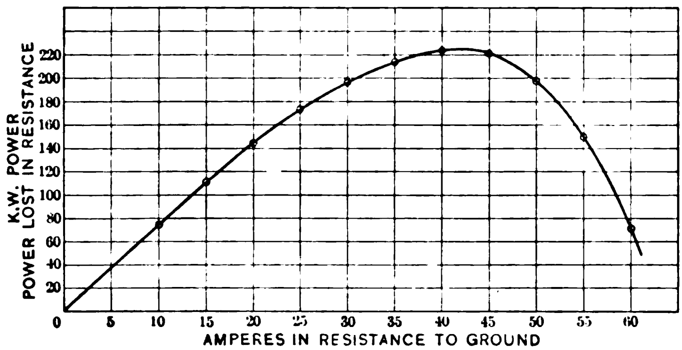


FIG. 27

culties seem insurmountable and unsolvable by any of the devices that have been described in scientific literature. From a standpoint of utilization of the current of the fault to ground, it is interesting to note that the value is only 77 milliamperes. When one considers that the load current on the system is several

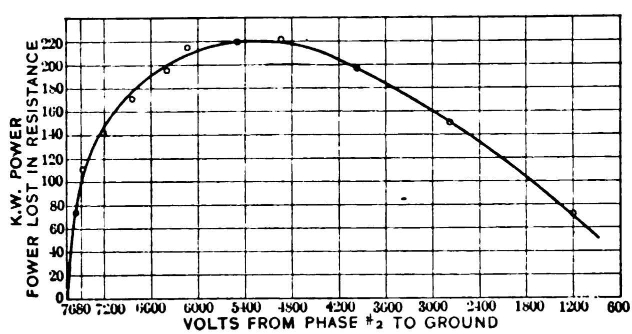


FIG. 28

hundred amperes, and the electrostatic charging current five amperes or more per cable, the difficulties in this approach to the problem are obvious. It is evident that for large systems the solution in sight is either to allow the fault to develop when it will and take care of it with the arcing ground suppressor, or to utilize the following proposed method:

Predetermining the Faults in Cable Systems. Experience shows that practically all the faults in a cable system develop initially between a single phase and ground. If the arc is not extinguished the arcing ground will very quickly burn the insulation between phases so badly as to cause a short circuit. In fact, this is what has always taken place when a fault has occurred on a cable system. There are certain weaknesses and accidents that cannot be foreseen, and the arcing ground suppressor with the localizer seems to be the only practicable solution in sight at present. There are, however, many faults which can be prematurely developed at a time most convenient to the operating engineer. Operators have often need to paraphrase an old saying in the form: "Grounds never come singly." One arcing ground will set up surges which will weaken other parts of the cable system, and these weakened points will subsequently develop into grounds. From experience in the laboratory, and from our knowledge of the phenomena, it is evident that most of these faults develop very gradually in the early stages. Laboratory experience shows very convincingly that insulation will stand a fairly definite limiting potential without any deterioration. Also, that slightly above this limit the deterioration is exceedingly slow, but becomes more and more rapid, along a descending logarithmic curve, as the potential across the insulation is increased more and more. If a test potential for a cable is chosen at a value that is less than the deteriorating value, then there can be no objection to applying it as frequently as desired. If, while this test potential is applied, there are inherent faults in the insulation which are still in their early stages of development, then the higher potential will hasten the development of these faults. Any inherent fault, then, may be developed at a time of the day and week when it is most convenient to make repairs, and when a spare cable may be substituted for the faulty one with the least inconvenience and disturbance in handling the load. To meet this situation, then, it is proposed to introduce at an artificial neutral, direct-current potential which will raise the total potential of the entire system by a specified amount above ground. Faults which stand this strain for several minutes are not likely to develop at normal potential within several days. The application of such a method would, we believe, tend greatly to keep the system free of incipient or embryonic faults. It is a refinement which, in the future, perhaps, may find considerable application. The assumption

is made that some faults will always develop in cables due to inherent weaknesses and age, or due to troubles which may come from electrolysis of the sheath. It is then, reasonable to develop these unavoidable faults at the most convenient time without switching or disturbance of the load. Plans are being made to apply this method.

Insulation Resistance of the System of the Public Service Electric Company

This system consists of both overhead and underground construction. A statement has already been made that the insulation resistance under normally safe conditions of operation varies from 2,000 ohms to 500,000,000 ohms. While Mr. A. H. Davis was making a study of the factors involved in the design of a localizer, he carried on, incidentally, continuous tests of the insulation of the system. The results show several features of interest.

The tests were made along the lines proposed above, that is, a direct current was applied at an artificial neutral formed by three potential transformers. In series with this direct-current generator was a recording ammeter. The current was kept within the range of the ammeter by different values of direct-current applied. Some typical results are shown in the following plotted curves of the *resistance of insulation* of the system as ordinate, and *time* as abscissa. Since the range of insulation resistance was so very large, a special method of plotting the curves was used. Three scales are used in the ordinates. These scales are placed one above the other, but there will be no difficulty in reading the resistance in the usual way by jumping from one scale to the next where the changes in resistance require it. The diurnal variations which actually took place are shown in these curves,—also the variations in resistance from minute to minute when the insulation resistance was low. The needle of the recording ammeter under these conditions moved over a very wide range. Low resistance invariably came from the overhead lines and was due entirely to weather conditions. The resistance varied according to the variations in the precipitation. Resistance might be of a medium high value, and a fog, or slight precipitation, might cause changes from minute to minute over a small range. When there was a steady downpour of rain over all the insulators, then the resistance became very low and unsteady. This may have been largely due to spattering of water

up under the petticoats of the insulators. The measurements brought out one interesting condition that has been noted elsewhere, but so far as the writer knows, never measured. Just before sunrise there is nearly always a sudden drop in the insulation resistance. A little later the insulation returns to a fairly high value. This is explained by the fact that when the sun rises the temperature of the atmosphere around the insulator is above the temperature of the insulator. In other words, the insulator absorbs heat more slowly than the air does. This

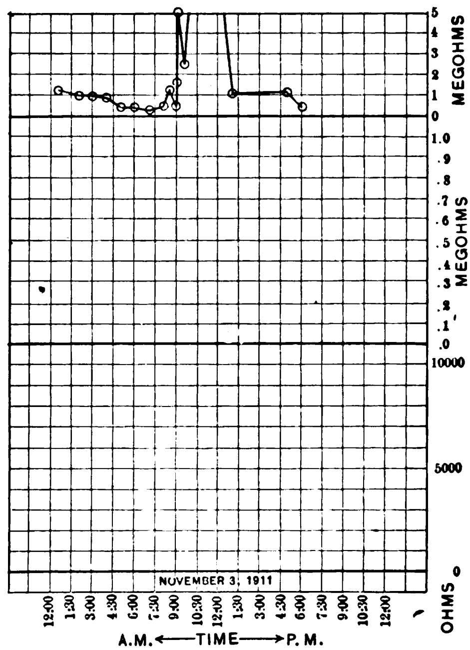


FIG. 29

leaves a cold insulator in contact with a more or less moist atmosphere and the result is a precipitation of dew on the surface of the insulator. This dew lowers the insulation resistance. Later, the insulator takes the same temperature as the ambient atmosphere and again dries off, which restores the insulation to its previous value. The tendency of insulators to break down at sunrise was noted years ago on some Mexican lines. Typical curves of the insulator resistance of the system are given in Figs. 29 to 34.

The insulation resistance on one day (Fig. 29) ran above 100,000 ohms. Between the hours of 10:00 and 12:30 the insulation ran above five megohms. The day was clear and the atmosphere fairly dry.

The curve of insulation resistance two days later as shown in Fig. 30 has a medium value all day. In the early morning between 1:30 and 3:00 o'clock there was either a shower or heavy fog. This we have indicated on this curve by zigzag line in imitation of the movement of the ammeter needle over the same

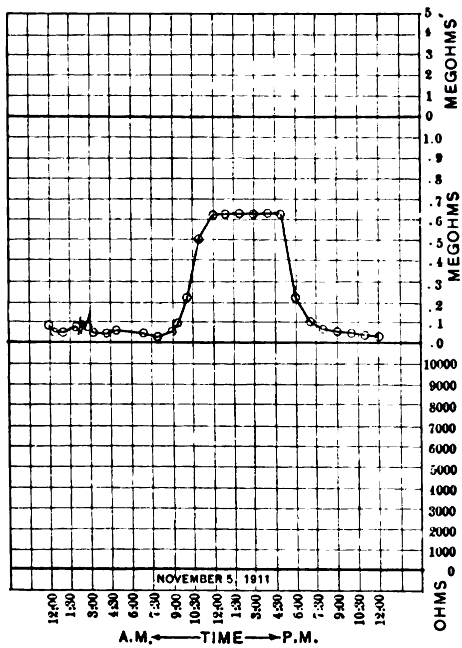


FIG. 30

period of time. The insulation varies from 300,000 ohms to 600,000 ohms during the day. As in the previous figure the insulation increases during the middle of the day, although, due to the moisture in the atmosphere, the actual value of resistance is not nearly so high as shown on the previous figure. The day was cloudy.

The resistance during the next day (Fig. 31) is typical of bad weather. Along about 5:00 o'clock in the morning there was evidently a light shower. At 9:00 o'clock the resistance became so low that the deflection of the ammeter went off the scale.

This condition of the meter was not corrected by lowering the voltage until 1:30. During this time the resistance dropped from 100,000 ohms down to 7,000 ohms. There was a shower about 2:00 o'clock, another one at 4:30, and another at 9:00 p.m. During this entire time the resistance was varying up and down over a wide range, as indicated in this figure by the zigzag lines. The lowest resistance of insulation recorded during the day was 3,000 ohms.

The record in Fig. 32 was taken on the following day. It rained

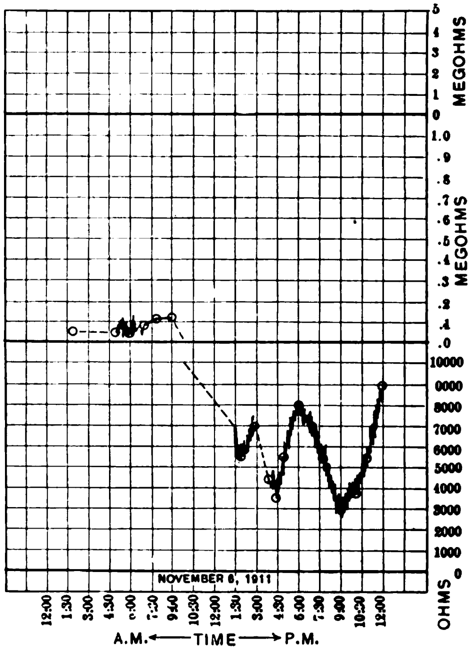


FIG. 31

heavily in the early hours of the morning but cleared up in the afternoon and dried off sufficiently to carry the insulation resistance from 5,000 ohms at 4:00 a.m. to 5,000,000 ohms at 5:00 p.m. Part of the record was lost during the middle of the day due to the lack of adjustment of the voltage on the recording ammeter. The variation of resistance was so great as to require a variation in the direct-current potential in order to keep the needle of the ammeter on the scale.

The record in Fig. 33 was taken two days later. It is typical of the usual cloudy weather conditions and illustrates a condition

of precipitation of dew already referred to. At 3:00 a.m. moisture in the atmosphere begins to make itself felt and the resistance drops from 650,000 ohms to 100,000 ohms at 7:00 o'clock. The dissipating effect of the sun's rays then begins to make itself felt and the resistance of the system rises rapidly and reaches a value of about one megohm at 9:00 a.m. While the sun is directly overhead the resistance remains high but at 3:00 p.m. the insulation resistance again drops and reaches a value of 200,000 ohms at 6:00 p.m. Due probably to a favor-

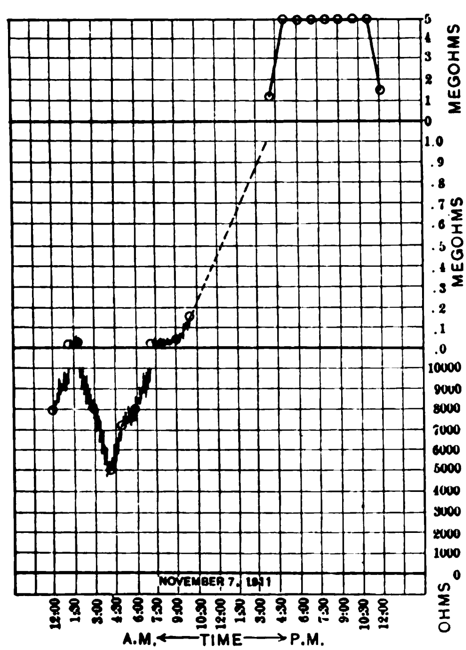


FIG. 32

able dry wind the insulation rises again until 9:00 p.m. but drops rapidly thereafter and reaches a value of less than 100,000 ohms by midnight.

The record of a later day (Fig. 34) illustrates a condition that is difficult to explain. During the early morning hour the resistance ran low but steady. At noon time it began to rain. At 5:00 o'clock the rain ceased and the resistance rose rapidly to over two megohms, but dropped in a few minutes back to its former value. This same condition was repeated five times up to midnight. There is a possibility that this variation might

have been due to a fault in the measuring apparatus such as might result from some accidental condition of contact between the brushes of the direct-current generator and the commutator. Considerable variations have been noted, although not as great as shown here, due to the passing of a cloud and a burst of sunshine, but this could not be the explanation here. In this case such a variation might also be caused by the accidental contact of a live wire with the limb of a tree, which was removed during short intervals. In such case the limb would finally be burned

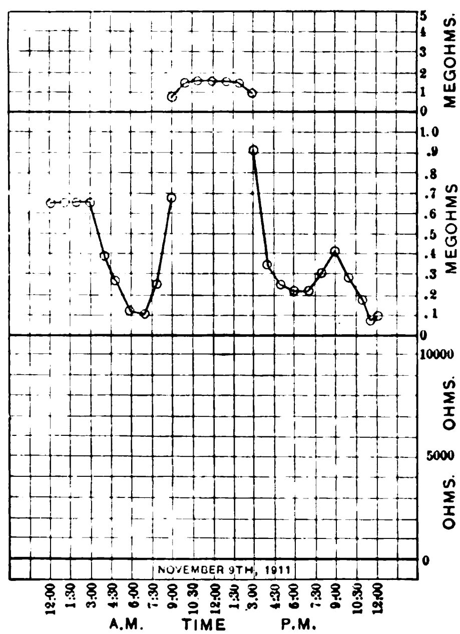


FIG. 33

away and leave the insulation high. One of the above conditions, we suppose, accounts for the form of these resistance curves.

SOME CHARACTERISTICS OF THE ARC IN THE ARCING GROUND ON A CABLE

Those who have made observations on the length of time required for an arcing ground to develop into a short circuit, and also on the difference in the destructive effect of arcing grounds occurring at different times and different places, cannot help

but be impressed by remarkable differences. If we compare the accidental arcs of one system with those on another, naturally we will expect to find different harmonics. Furthermore, due to differences in electrostatic capacity, different values of grounding current will also occur. These fundamental differences will naturally give different effects. The cause of the difference is not so evident, however, when we consider arcing grounds on the same system at different times, when, apparently, all the conditions of generation and capacity are identical.

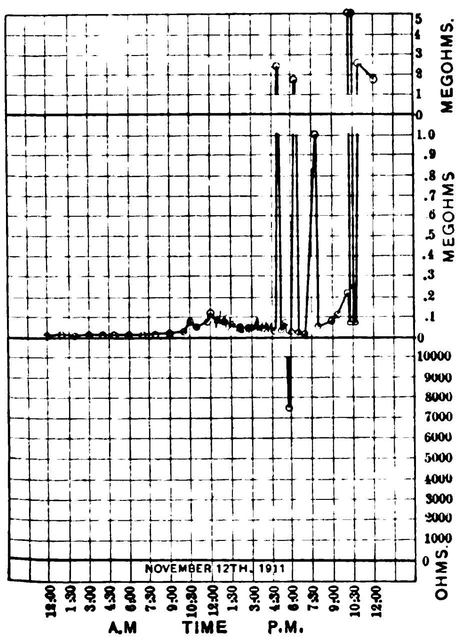


FIG. 34

In discussing this subject it might be well to bring up at this time the possibilities of variations coming from the reactions of the receiver apparatus on the circuit, such, for example, as synchronous motors, induction motors, etc. The presence of these machines has to do with the harmonics, but apparently has no effect on the duration of the accidental arcing ground before it burns into a short circuit. This latter seems to depend very greatly on the peripheral location of the accidental arc on the sheath of the cable. If, on the one hand, the arc should take place on the under side of a horizontally placed cable, the melted

lead from the crater of the arc would drop down and there would be a tendency to melt the lead away from the fault, and thereby constantly increase the arc length. We know that a varying arc length will cause a magnification of different high frequencies. On the other hand, suppose the accidental arc takes place on the upper side of a horizontally placed cable, then the melted lead from the sheath will tend to run into the punctured hole in the insulation and make a direct contact from the faulty phase to ground. If the charging current is not large, then the lead in a solidified form may have sufficient conductivity to radiate the I^2R given to it by the grounding current. The extinguishment of the arcing ground in this case will cut off the surges and a system would be able to run for hours without interference to the power service. If, however, the lead from the sheath which melts and runs into the hole is not quite sufficient to carry the grounding current it will be continually breaking up, forming a short arc which melts more lead, which in turn again shortens the arc. In other words, there will be an intermittent arc to ground. The duration of the fault before it burns into a short circuit may still be many minutes.

By taking into account the possible variable locations of the three phases relative to a vertical line, and the variable peripheral location of the arc on the sheath, it seems possible to explain many of the different effects that have been obtained on the same system with different accidental arcs to ground.

Another factor is the peripheral location of the fault on the insulation of a single phase. If the fault should occur where the insulation of the two adjacent phases come in contact it will, naturally, burn into a short circuit much more rapidly than if the fault should occur at a point nearer the lead sheath.

Another condition that will cause differences in transient potentials has been mentioned in previous papers. This difference comes from the location of an accidental arcing ground relative to the length of the feeder. Like the light touch of a finger on a violin string which makes it vibrate on high notes by oscillations in sections, the same condition may occur electrically on a feeder. There are certain locations on a violin string where a light touch will simply dampen the vibrations. Apparently there exists the same condition in the electrical circuit. There are, however, many places on the violin string which give different clear high tones, and by analogy, there are the same conditions on the electrical circuit. If any one of these high

frequencies happens to resonate with some localized inductance and capacity in the circuit, damage results. This is mere chance and is a condition which, happily, does not occur often during accidental grounds.

When a short circuit takes place which is not the result of the development of an arcing ground it usually occurs at a defective joint. In order to give the arcing ground suppressor a maximum efficiency in preventing interruptions of service, special care should be taken to prevent weakness in the joints. A difference has been noted in the strength of joints on different sections of a system which result from a difference in the policies of the repair foremen. On one section the foreman makes a

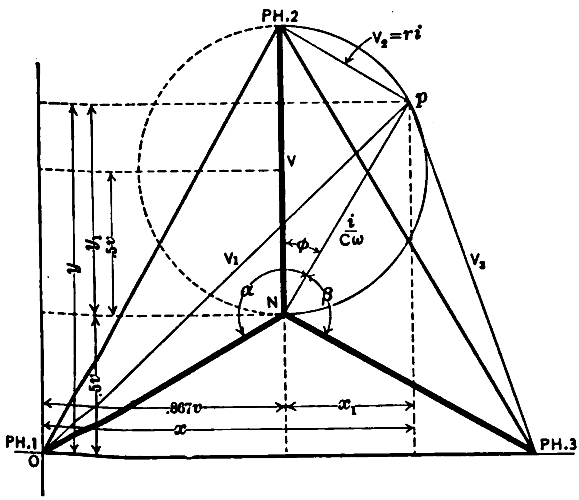


FIG. 35

repair just as soon as it can be done at any time of day or night. On the other section the foreman waits for daylight and other favorable conditions of the atmosphere and weather. The foreman who waits for propitious conditions has fewer breakdowns in joints than the one who pays less attention to the conditions. If it is assumed that each is equally conscientious in his work, and that no other factors enter, the extra care seems very much worth while.

SUMMARY

Generators on a *loaded* three-phase system maintain practically constant delta potential between phases. The generators

themselves generate nearly constant and stable Y potentials. Any shifting of the neutral of the generator on a loaded system is transitory. The values of potential of the three phases to ground are determined by lines drawn from the corners of the delta triangle to a point on a semicircle drawn on the Y potential as diameter. This semi-circle is drawn on the side of the Y potential next to the succeeding phase (see Fig. 35). For example, if phase 2 is grounded the semi-circle is on the side of phase 3.

In the oscillograms of the operation of the arcing ground suppressors, no dangerous potentials were observed. The suppressor operates in one-quarter of a second in accordance with the usual design of switch.

Different harmonics were found on the system, namely: 11, 13 and 17, which were magnified more or less according to the conditions of capacity. In themselves, these harmonics have no baneful significance.

The effects of an arcing ground on a cable are modified by movements of the melted metal of the lead sheath. On the under side the lead drops away and thus increases the arc length. On the upper side the molten metal runs down into the fault and shortens the arc.

For a certain value of resistance to ground, the value that drops the potential to ground by about one-third, the loss of energy in the fault is a maximum of 220 kw.

A method of predetermining faults in the insulation while the system is in normal operation, is proposed, in which high potential direct-current is applied at the neutral, protection being given by arresters, suppressors and localizers.

All the protective effects of a grounded neutral may be obtained by connecting aluminum cells between the generator neutral and ground and, at the same time, all the objectionable effects of short circuits and cross currents that attend a grounded neutral are avoided.

The insulation resistance of a mixed overhead and underground system is determined almost entirely by the relatively high leakage over the insulators. Weather conditions changed the insulation from 5,000 ohms to over 500 megohms.

A paper presented at the 29th Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June 28, 1912.

PERMEABILITY MEASUREMENTS WITH ALTERNATING CURRENT

BY L. T. ROBINSON AND J. D. BALL

In testing samples of sheet iron to determine whether or not the material is suitable for the specific purpose for which it is intended, it is desirable to know the core loss in a unit volume of the material. The total core loss obtained may be separated by well known means into hysteresis and eddy losses or the total core loss without separation may be used as a measure of the quality of the material.

In designing apparatus it is also necessary to know with some degree of accuracy the permeability of the material.

Accurate measurements of permeability may be obtained by various methods, and approximate methods of practical value have been employed in which the ballistic galvanometer is not used, but for the most part these methods require that the sample under test be put through the permeability tests on direct current.

It is desirable to find means to measure permeability with accuracy and speed comparable with core loss measurements, and as core loss measurements are made on alternating current, a method using the same current supply as that used in making this test is sought.

The present paper deals with the general relations between maximum flux density, maximum exciting current and magnetizing current.(1) The method has not been completely developed to deal with samples in the form of bundles of strips. The preliminary work referred to was confined to ring samples but the general principles involved may be used later in dealing with samples of standard form.(2)

In a sample of iron magnetized by an alternating current the maximum magnetizing current occurs quite obviously at the point of maximum flux, which is the point of zero induced voltage. The total primary current, however, contains eddy components which may include currents for supplying instruments, *e.g.*, a voltmeter for measuring the magnetic density, connected to a secondary winding, as well as eddy currents in the iron.

We will write I_m for the maximum magnetizing current.

I_e for the maximum exciting or total current.

I_w for the maximum eddy current, including any currents in the secondary.

i_m, i_e and i_w will be used to represent the instantaneous values of the above quantities.

For the present only samples will be considered in which the laminations are thin enough so that appreciable "screening" does not occur. The eddy current i_w may be considered to be exactly in phase with the induced voltage and therefore to pass through zero when the magnetizing current is at a maximum.

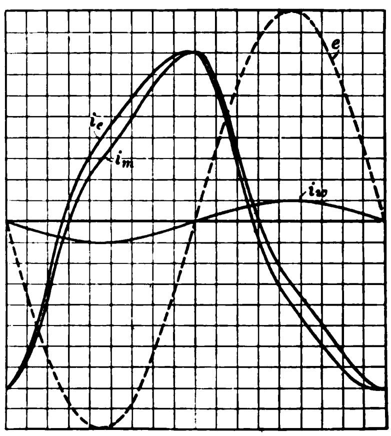


FIG. 1

Therefore the instantaneous value of the primary current i_e which occurs at the instant that the induced e.m.f. passes through zero represents I_m, the magnetizing current to be used in plotting the *B-H* curve. *B* may be directly determined by voltmeter if sine wave of e.m.f. is employed and wave distortion does not occur in the apparatus. The distortion of secondary e.m.f. wave has been carefully considered in connection with the commercial apparatus already referred to and need not be discussed here.

Under some conditions the maximum magnetizing current very closely coincides with the maximum total primary current. The condition of coincidence will occur when the sinusoidal eddy and secondary component of the total primary distorted wave does not at any point exceed the difference between the magnetizing current at that point and the maximum magnetizing current.

While this relation is somewhat difficult to express concisely with words or symbols it is very quickly shown by reference to the figures and oscillograms which follow.

Fig. 1 shows an induced e.m.f. wave, a magnetizing current wave i_m derived from a hysteresis loop and an assumed energy wave i_w in phase with the induced e.m.f. A wave of total current i_e derived from the magnetizing and eddy waves is also shown. It will be seen from this figure that I_e is identical with I_m because the eddy current is at no point greater than the difference between i_m and I_m.

Fig. 2 is the same as Fig. 1, except that the eddy current has been assumed to be larger and in consequence the exciting current is larger. In this assumed case it is seen that I_e is greater than I_m and the assumption that they are alike would lead to an error of about 12 per cent.

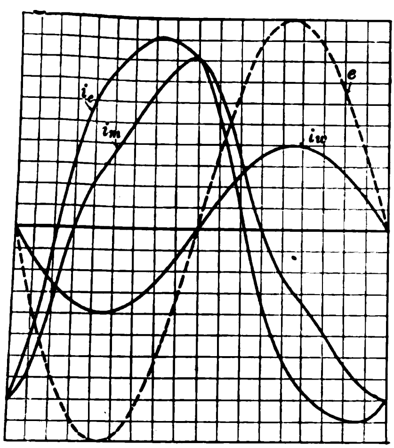


FIG. 2

Figs. 3 to 7 inclusive are records of current and induced e.m.f. at various inductions. The sample was of 0.014-in. (0.035 cm.) thick iron and weighed about 22 lb. (10 kg.) The material was high-resistance iron which was selected because several careful ballistic determinations for permeability and hysteresis had been made on the sample in connection with some earlier work.

Perpendiculars have been drawn from the point of zero voltage intercepting the exciting current curve at the point of maximum magnetizing current. From these and similar records the assumption for this sample that $I_e = I_m$ is in error by the following percentages:

B	60~ per cent error	25~ per cent error
14,150	0	0
12,140	0	0
10,075	2.5	0
8,315	2.52	0.81
5,000	1.8	0.64
2,861	1.77	0.53
2,020	1.41	1.41
999	0.78	0

In order to show the relationship more fully the current and voltage of Fig. 4, $B = 10075$, 60~, are plotted together with the magnetizing current wave and hysteresis loop, Fig. 8. Subtracting the values of i_m from i_e and plotting the differences gives, as expected, a wave in phase with the induced e.m.f. and of form approximately sinusoidal.

Taking the effective value of this wave and of the voltage wave we obtain a value for the watts loss, which was found to agree closely with the watts consumed in the voltmeter plus the eddy current loss as determined by separation tests. The

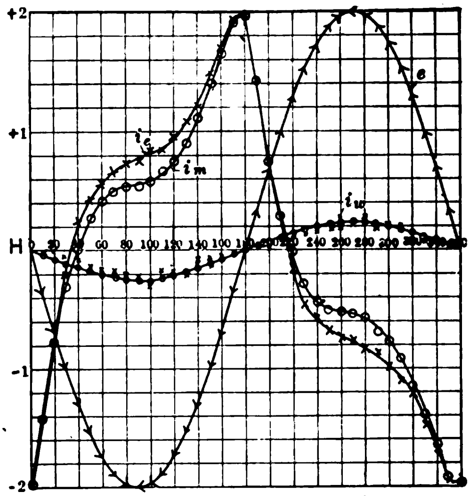


FIG. 8.—SAME SAMPLE AS FIG. 3. CURVES FOR e AND i_e TAKEN FROM FIG. 4. CURVE FOR i_m DERIVED FROM HYSTERESIS LOOP (BALLISTIC). Points marked X on i_w curve are derived from i_m and i_e. Points marked 0 are for sine wave.

loss on the oscillograph circuit was included with the voltmeter loss. In order to reduce this loss as much as possible the oscillograph vibrator used for taking the voltage wave was connected to a separate winding having two to four turns and a very small resistance was included in the vibrator circuit.

Oscillograms for all densities given in the preceding table were taken both at 60 ~ and 25 ~ but only representative ones are shown.

The accuracy of these results was tested by determining *B-H* curves in the usual manner with ballistic galvanometer and the general agreement between the results is shown in Fig. 9. The agreement is not what could be considered entirely satisfactory,

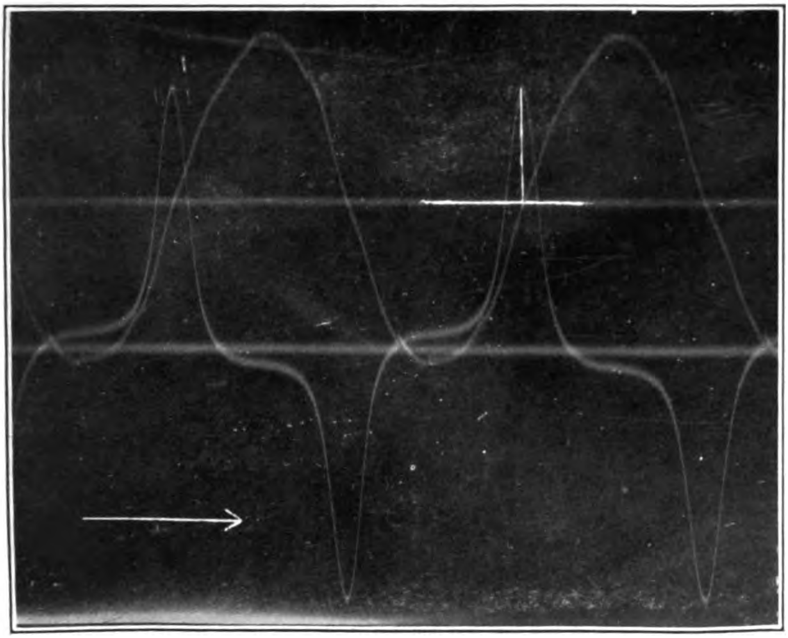


FIG. 3. [ROBINSON AND BALL]

Primary current wave (lower curve) and secondary induced e.m.f. (upper curve) on 22-lb. ring of 0.014-in. iron at 60 cycles per sec. Voltmeter resistance 1800 ohms—Induced voltage 116.5—B maximum 14,150, I_m 5.27, I_e 5.27, H = 14.63.

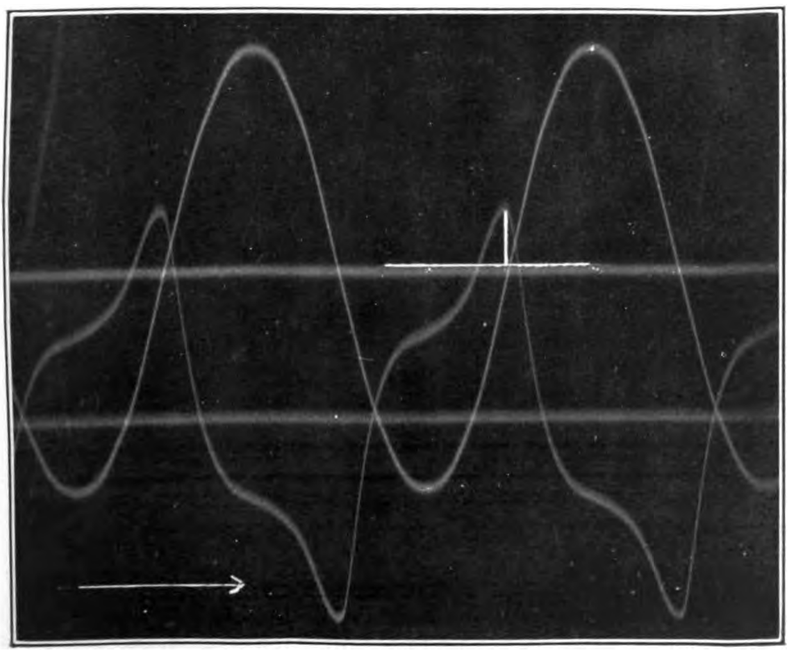


FIG. 4. [ROBINSON AND BAL.

Same sample as Fig. 3. Voltmeter resistance 1800 ohms—Induced voltage 82.9—B maximum 10.075, I_m 0.707, I_e 0.730, H = 1.?8.

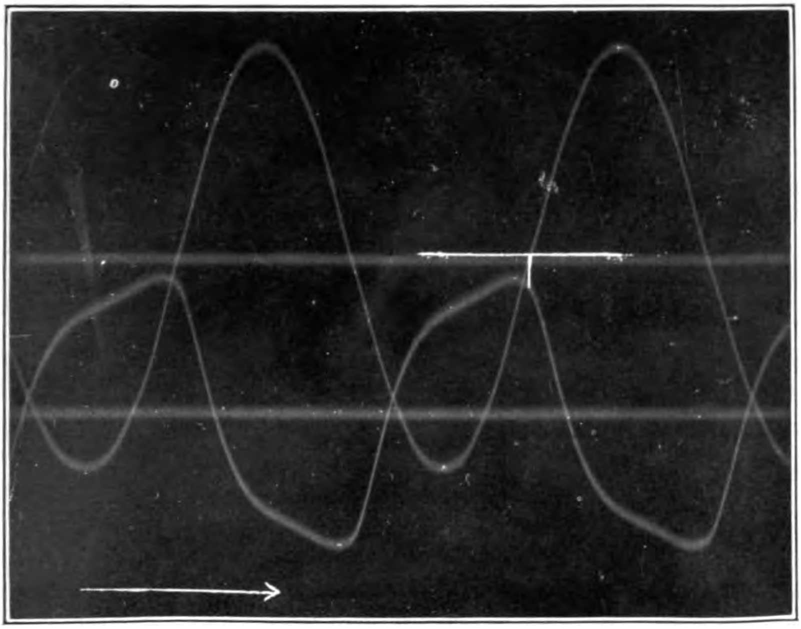


FIG. 5. [ROBINSON AND BALL]

Same sample as Fig. 3 Voltmeter resistance 1800 ohms—Induced voltage 41.2—B maximum 5000, I_m 0.260, I_e 0.264, H = 0.722.

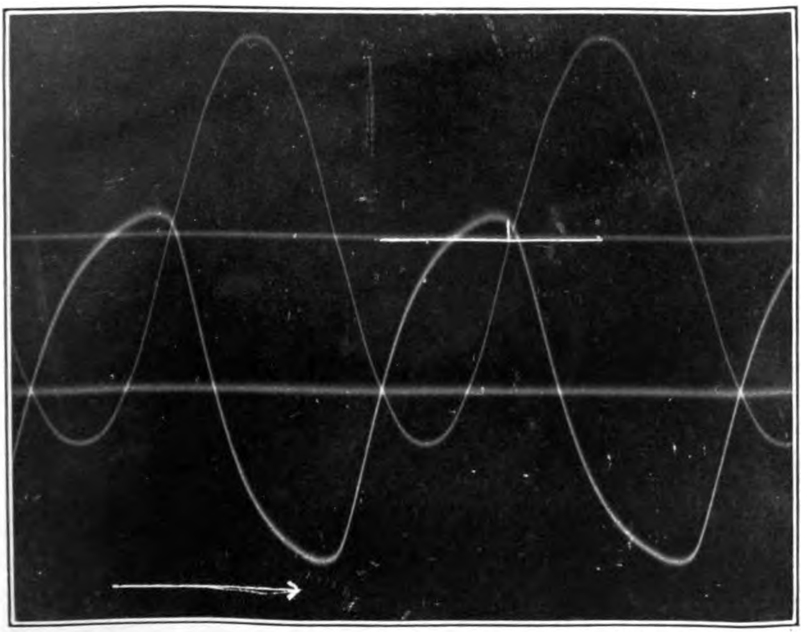


FIG. 6. [ROBINSON AND BALL]

Same sample as Fig. 3. Voltmeter resistance 4200 ohms (reflecting dynamometer)—Induced voltage 16.6—B maximum 2020, I_m 0.178, I_e 0.181, H = 0.496.

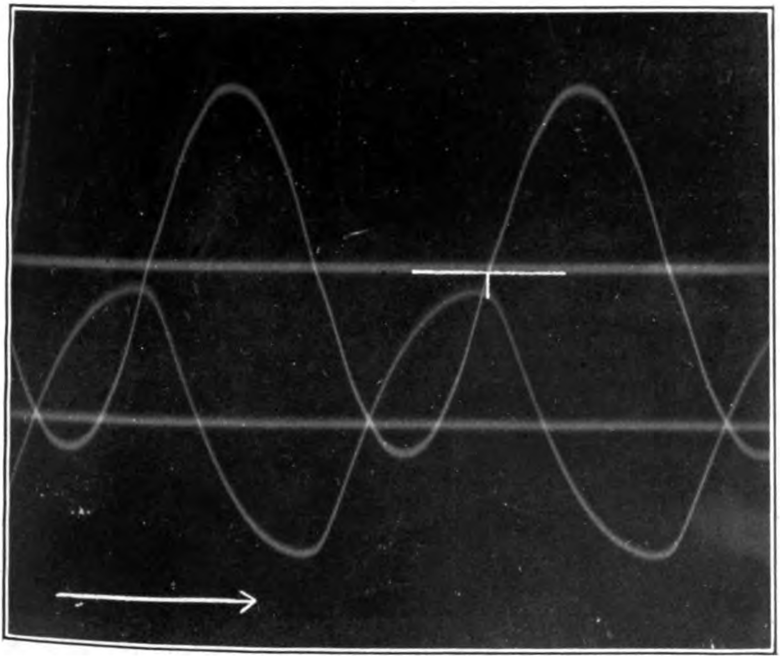


FIG. 7. [ROBINSON AND BALL]

Same sample as Fig. 3. Voltmeter resistance 2000 ohms—Induced voltage 8.16—B maximum 993, I_m 0.137, I_e 0.138, H = 0.381.

as final values, but is sufficient to establish the fact that the preceding general conclusions are substantially true.

There remains to be determined by convenient means the value of I_e. The taking of an oscillogram for each induction is prohibitive in practical work, therefore tests were made with the oscillograph by observing for each induction the width of the band of light coming from the vibrator which was connected into the current circuit. The width of this beam corrected for the width of the spot as observed in the zero position is a measure of twice the maximum exciting current, which is

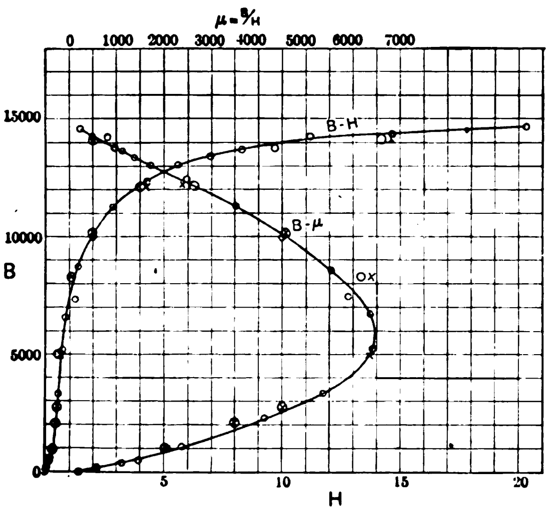


FIG. 9.—SHOWING *B–H* AND PERMEABILITY CURVES, SAME SAMPLE AS FIG. 3

X = 60 cycles per sec.; *O* = 25 cycles per sec.; *o* = direct current.

evaluated by means of a d-c. calibration of the vibrator. Additional tests, similar to Fig. 9, were made on similar material, observing the width of the beam, and better results were obtained (see Fig. 10) than those found on the sample of Fig. 9, which was shown because waves and ballistic loops were available on this sample. A sample of low resistance unalloyed iron was tested showing a-c. and d-c. results not in good agreement between $B = 4000$ and $B = 10,000$. This would be expected in a sample having high permeability accompanied by relatively large eddy loss.

Conclusions

The measurement of maximum current (I_e) by elementary oscillograph, observing the width of the beam, is satisfactory and furnishes a convenient and fairly accurate means for determining the values in any work where the maximum rather than the average or effective value of a current or voltage is required.

The assumption that I_e represents I_m, in all cases, is not warranted, due to the causes explained, and further investigation is required before the limits of thickness of lamination, permeability, relative eddy loss, shape of hysteresis loop, etc. which can be successfully handled are definitely determined. The samples experimented on, particularly Fig. 10, were, by reason

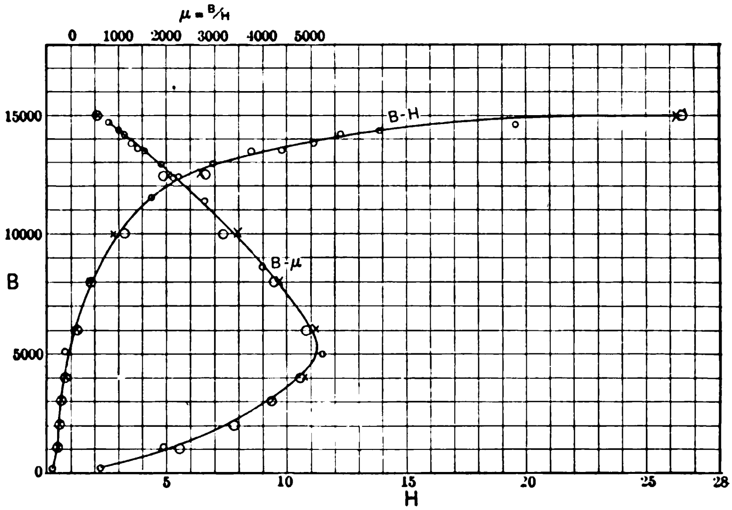


Fig. 10.—Showing B–H and Permeability Curves, Same Data as Fig. 9, on a Different Sample.

of relatively high hysteresis loss, low eddy current and medium permeability, well suited to obtaining good results by the method used, although the oscillograms show that the total primary current tends to reach a maximum in excess of the maximum magnetizing current.

The investigations will be continued in the hope of finding that the limits of practical application are not too narrow to be of value.

References

1. During the progress of this work some results of a similar investigation were published under the title "A method of

measuring permeability by means of alternating currents" by R. Beattie, D. Sc., and H. Gerrard, M. Sc., *Electrician* (London) Vol. LXVIII, No. 11, pp. 436–438, Dec. 22, 1911.

A very interesting method is there presented for determining the maximum primary current by measuring the watt loss in a small iron core which has been calibrated previously and whose primary winding is included in series with the exciting winding of the sample to be tested.

The fact that the maximum primary current may not always represent the maximum magnetizing current is not referred to in the article and the authors of the present paper believe that the determination of maximum current by observing the width of band on the elementary oscillograph is more convenient than the method proposed by Messrs. Beattie and Gerrard. The fact referred to in a footnote by Beattie and Gerrard that *B-H* curves on alternating current lie below those of direct current may be accounted for in part by the fact that secondary and eddy current may raise the maximum of the exciting current and consequently cause too large *H* values to be plotted on alternating current.

2. The standard sample according to the specifications of the American Society for Testing Materials is the same as that used in the Epstein apparatus, viz. 50 by 3 cm. (19 11/16 by 1 3/16 in.) weighing 10 kg. (22 lb.) and divided into four equal bundles.

A paper presented at the April 5th Meeting and discussed at the 29th Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June 26, 1912.

THE RELATION OF CENTRAL STATION GENERATION TO RAILWAY ELECTRIFICATION

BY SAMUEL INSULL

I am not going to discuss the question of the practicability of steam railroad electrification. That is not a matter at all within my province. That is a matter that has to be decided by those great captains of industry who are in control of the vast transportation companies in this country from the Atlantic to the Pacific. But it is reasonable, as a central station man, that I should assume that the electrification of steam railroads has come to stay, that the work done by the two premier trunk lines centering in New York is a sufficient indication of what we may expect in the future. I am not in sympathy with an agitation to force the steam railroads in this country to electrify. That is a question of the provision of the capital necessary for the purpose, and that question must be taken up and settled by those who are responsible for the operation of the railway properties.

Nor am I going to discuss what might be termed the technique of the electrification of steam railroads; that is, the special system that should be used, whether it should be done with one class of current or another, or one pressure or another. The system finally decided on must be the one which fills conditions of railroad operation, and at the same time renders it possible for the railroad company to take advantage of the sources of energy supply already existing, as the railroad demand is only about 15 to 20 per cent of the total demand for energy in any community. That amount of energy which the railroads require to operate their properties is really the thing that should turn them to central station men for assistance, and I speak as a central station man.

The amount of energy required to operate the terminal and suburban systems of all the trunk lines centering in and around New York City (as I think I will be able to demonstrate to you) is, I believe, less than the amount of energy required to operate the isolated electric lighting plants in the same territory. It is not a serious proposition. To my mind it is of less consequence to the properly operated electricity supply company than the isolated plant business was to the electric light and power companies through the country twenty years ago, or even fifteen or ten years ago.

The problem of the relation of the central station to the generation and primary distribution of energy, so far as the steam railroads are concerned, is a question of economics. It cannot properly be considered without taking into account the entire question of generation and primary distribution for any given center of population. If you consider steam railroad electrification by itself, the amount of energy required seems to be very great indeed. If you consider it merely as a fraction of the supply of energy required by a community for all kinds of purposes, it is found to be simply an incident. Perhaps a more accurate title for this paper would be "The Generation and Primary Distribution of Energy for Given Areas," because that is the real question involved. It is not a new subject; it is a subject dealt with at great length in the inaugural address of 1910 by my friend Mr. de Ferranti, when addressing our sister organization, the British Institution of Electrical Engineers. Mr. de Ferranti went further than I am going in this discussion, and proposed a scheme of generation and distribution for the whole of Great Britain. He proposed a scheme that meant, in his opinion, a saving of 80,000,000 to 90,000,000 tons of coal a year for Great Britain. If the plan, which you must necessarily admit is reasonable, after studying the maps and curves presented, were adopted, my judgment is that it would mean the greatest conservation of one of the most important natural resources of this country, namely fuel, to the extent, probably, of from 200,000,000 to 250,000,000 tons of coal per year.

The method of concentration of generation and distribution of primary power, as I said, is not a new subject. It has been an absolute necessity in all the smaller communities of this country. First, in the small communities they formed companies to do the public lighting; next they added to that the incandescent lighting business, a little later they added the power business, then

they connected up two or three small towns together, and to-day the average prosperous small local company supplies energy not only for lighting, whether for domestic or commercial or public purposes, but for power, for pumping water, and for the urban and interurban transportation, and as a result has raised its load factor from about 20 per cent, when it was engaged solely in the lighting business, to from 40 to 50 per cent to-day. That method of concentration of generation is going on to such an extent in the smaller communities throughout this country that I know of cases where, in an area of 15,000 square miles, that is, an area 150 miles one way by 100 miles another way, they seriously have in contemplation doing away with possibly 100 to 120 generating stations, and replacing them with ten or twelve stations.

Where there are large water powers adjacent to the larger cities, you find no hesitation on the part of the railway company, the electric light and power company, and the electrified steam railway company, if there be such, in that vicinity, in taking the energy from one source of supply. Is there any reason why the power generated at Niagara Falls can be used alike by all these enterprises, whether they be local public service enterprises, state public service enterprises, or interstate enterprises—is there any peculiarity about the fact that the power is generated hydraulically? Is that any special reason why these various industries should all take their energy from a given source? Is it not just as reasonable that they should all take their energy from a given source, if that power is supplied from fuel, from coal, with steam turbines as the prime movers, as that they should do this when the power is supplied from water with hydraulic turbines as prime movers? I cannot see any reason, if concentration of production is the correct principle in one case, why concentration of production is not the correct principle in every case.

I have naturally taken for the purposes of my discussion the information which the engineers of public service enterprises in New York have placed at my disposal, together with the information that I naturally am able to obtain from my own operations in Chicago, and the conclusion that I have come to is that the concentration of the production of energy, for all purposes required in a given area about any large center of population, would result in such a saving in capital, and such a saving in operating expenses, as to provide sufficiently for the generating capacity and primary transmission systems necessary to elec-

trify the terminal systems and suburban service of all the trunk lines centering in and around that center of population, (particularly is this true of New York) and such a saving as to yield very large profits, in addition, to the engineers and financiers having the courage to handle so great a problem.

The *percentage* of saving is comparatively small. On a percentage basis I may say that the percentage of saving in greater New York (by "greater New York" I include that part of the Jersey shore that would naturally be considered a part of a Greater New York,) is comparatively small, and to my mind somewhat disappointing, owing to peculiar conditions which I will explain later. But the saving itself is so large and amounts to such a vast sum of money, capitalized, that I cannot see how it is possible, whatever may be the jealousies of management, and whatever may be the individual interests of the financial people operating the various properties,— both as engineers desiring to get the greatest possible results out of their work, and as capitalists wanting to supply the greatest possible amount of service at the lowest possible cost to the public and the greatest possible profit to themselves, I cannot see how either the engineers or the financiers can neglect the subject and let it pass by, as it is one of the greatest opportunities I know of in our business.

To take up now the illustrative curves, Fig. 1 is the New York total load diagram. It includes the present electrical load of the central stations in Greater New York and the central stations on the Jersey shore, within a radius of ten or twelve miles of New York, operated by the Public Service Corporation of New Jersey, and the station of the Hudson and Manhattan Railroad Company.

The diagram includes only that portion of the load of the electrified steam roads which has already been electrified, and does not include an estimate of the load of the isolated plants. If the balance of the load of the electrified steam roads and the isolated plant load were included, the total would be in the neighborhood of 1,000,000 kw.

Looking ahead, if you take this New York maximum of 676,000 kw. and apply an 8 per cent annual increase (the actual increase of this maximum over the previous winter was 7½ per cent), at the end of eight years the New York maximum would amount to 1,250,000 kw., and at the end of ten years to 1,480,000 kw.

If there be added to these figures the isolated plant and steam

railroad demand, it makes about 1,000,000 kw. of load at the present time. The steam railroad demand would be about 170,000 kw. of that total, and the demand made by isolated plants would be 217,000 kw.

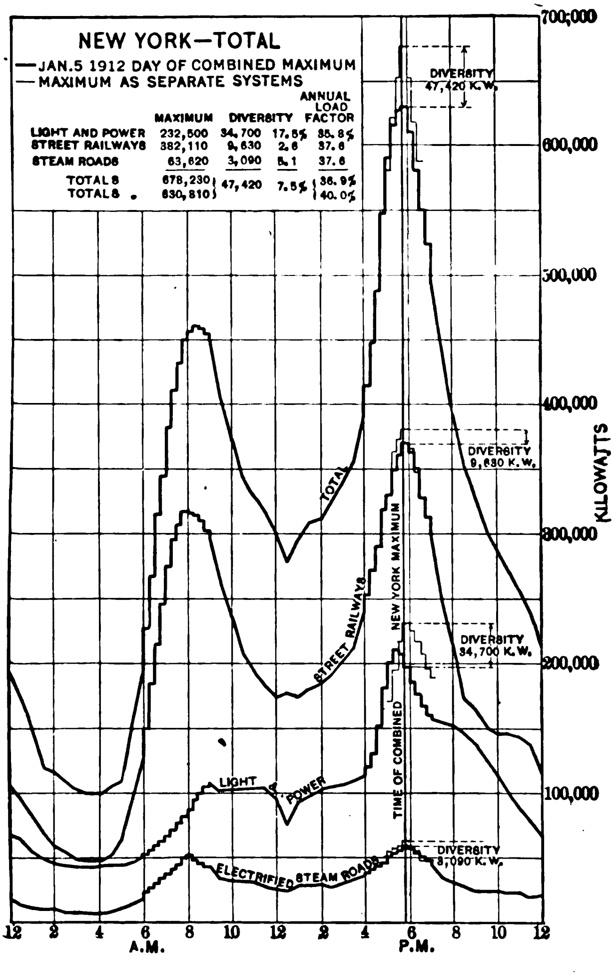


FIG. 1

The total load of the systems separately is 678,000 kw., and there is a diversity factor that would reduce that if they were all run as one system; that is, if the present business of the lighting and power companies, the street railways and the steam railways were combined, the maximum load this last winter would

have amounted to 630,000 kw., or a saving of upwards of 47,000 kw. The diversity factor amounted to 7.5 per cent, and the load factor would have been improved from 36.9 to 40 per cent. Later, I will explain some of the advantages obtained from that.

Fig. 2 is the New York light and power load diagram. The New York Edison Company curve includes the load of the

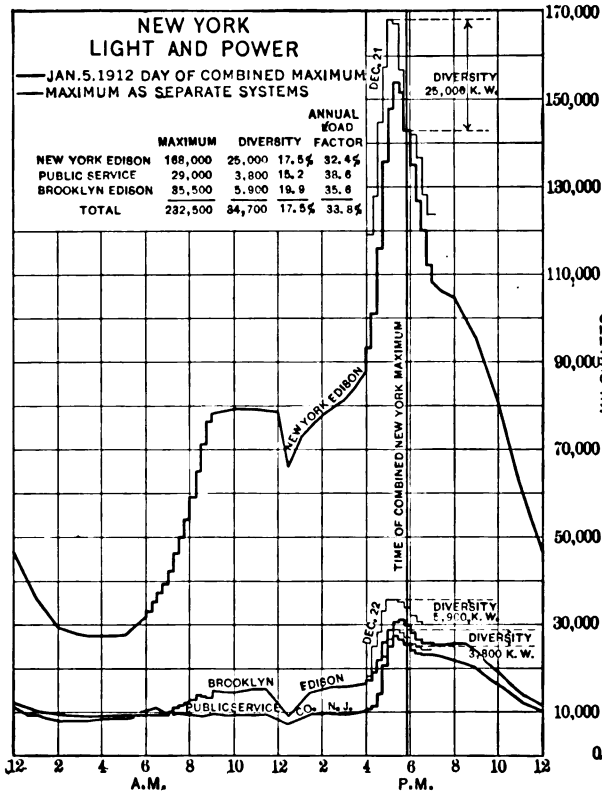


FIG. 2

United Electric Light and Power Company and also the Bronx load. The Public Service Corporation curve includes that company's light and power load only, its street railway load being on the street railway curve.

The total load is 232,500 kw. The load factor of the various systems by themselves is 33.8 per cent. There is a diversity of 17.5 per cent, amounting to 34,700 kw., between the sum of the

maxima for the year of these different lighting companies and their load between 5:45 and 6 p.m. on January 5, 1912, which was the time of the maximum for all of the New York companies combined, that is, the lighting, the street railway and the electrified steam railroad companies.

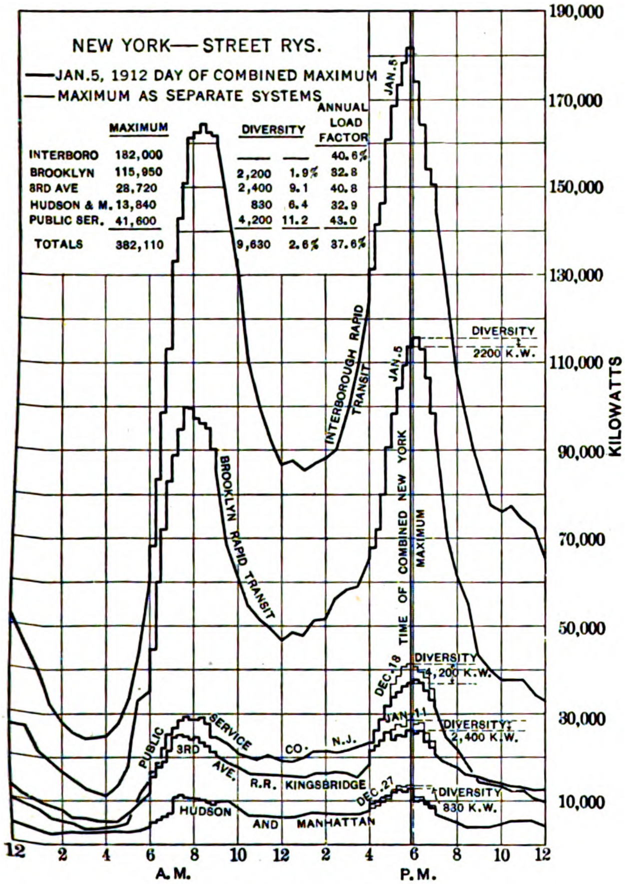


FIG. 3

Fig. 3 shows the load diagram of the street railways of New York City. The Interborough has much the largest maximum of any of the New York companies, and therefore establishes the day and hour of the combined maximum, and there is no diversity between the Interborough load and the combined maximum. The diversity between the three power houses, subway, surface

and elevated, of the Interborough has not been taken advantage of, and possibly amounts to a considerable figure. What is meant by that is that I have not taken advantage of it in making these diagrams, although the interests having charge of the street railways, I believe, have already taken advantage of it by connecting up their various power houses, so as to get the advantage of the diversity factor.

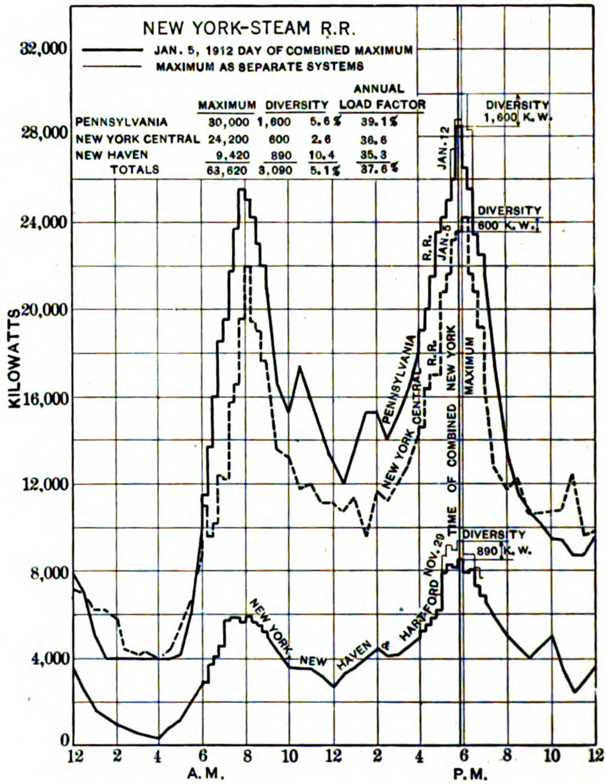


FIG. 4

Fig. 4 shows the load diagram of the steam railroads entering New York City. Due to the electric heating of the suburban cars, the New York Central maximum occurs on the same day as the Interborough and the combined maximum, and the Pennsylvania maximum, for the same reason, only a few days later.

The present electrical load for the passenger service of the steam railroads of New York is estimated at about two-thirds of

the total load if all of the passenger service within a reasonable radius of say fifteen to twenty miles of New York City were electrified. This would give for New York a total electrified passenger load of 95,000 kw., as compared with our estimate for Chicago of 73,000 kw., which appears reasonable. If to this we add 75,000 kw. for freight, as compared with our estimate for Chicago freight of 78,000 kw., we get a total for the electrified steam railroads in the vicinity of New York of 170,000 kw.

Attention might be called to the fact that the farther out the steam railroads are electrified, the less influence the suburban service will have and therefore the greater the diversity factor.

There is a very important point I wish to emphasize, that has a bearing on this subject only in the large centers of population where there is heavy suburban travel. The same thing will be shown in some of the curves to follow. These two maximum loads, morning and evening, are made up of suburban business, and the suburban railway load maxima are largely affected by the heating proposition, and also the large amount of power needed additionally for traction in cold weather. That condition cannot possibly exist except in a few, perhaps a dozen different cities of the United States. The steam railroad load factor is relatively poor in those centers, but if you will take the average business throughout the country where our central stations are in cities, say of the second and third grade, the steam railroad load would show a very much better load factor, as there is practically little or no suburban business in any cities except the very largest cities of the country.

Fig. 5 is the total load diagram of Boston. The street railway curve is the Boston Elevated Railway Company load, which includes the subway, surface and elevated roads. The Edison light and power load is also given.

A careful estimate of the electrical requirements for the passenger service only, for all the steam roads operating within the metropolitan district of Boston, has been made, but as the figures do not include freight, and also for the reason that the larger portion of it is based on 11,000-volt single-phase operation, which system practically eliminates the possibility of showing savings in transmission and substation by combining with the other local power supply, I have not attempted to include load curves for the electrified steam roads. Also no estimate has been made of the isolated plant load in Boston. The total capacity of the Boston steam plants, 160,600 kw., amounts to a reserve on the combined load of 68 per cent.

It will easily be seen that there is a remarkable diversity between the loads of the street railway and lighting and power companies in Boston. To me it seems almost incredible that there should be built a second large power station in Boston, when, if the service for both the lighting and railway were run

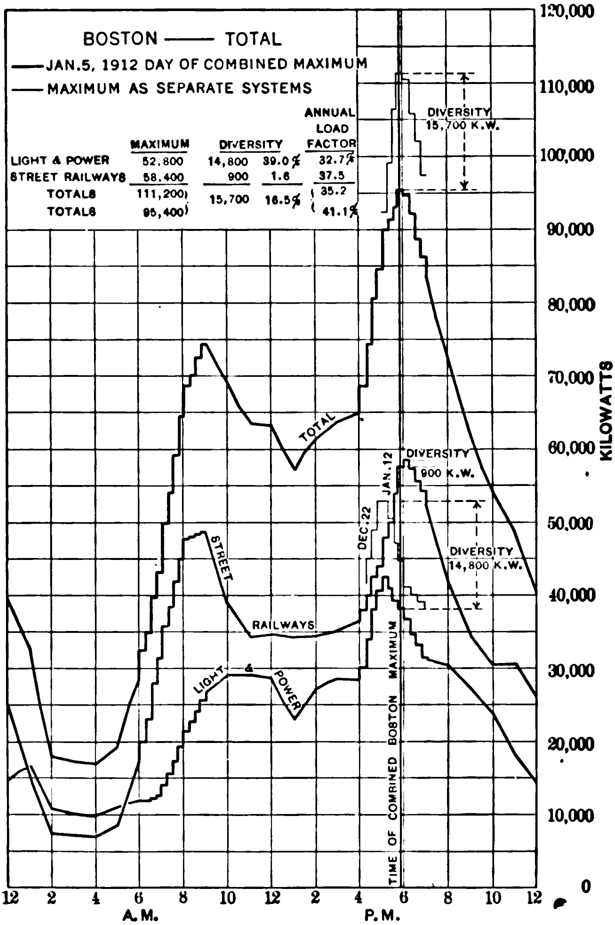


FIG. 5

by the same station, the maximum load last winter would have been 95,400 kw., instead of 111,200 kw., as there is a diversity of 16.5 per cent between the two businesses; and yet so blind are some people to their own interests, that the financial men running the Boston Elevated roads are actually throwing money away

by building a plant for themselves right by the side of the plant of the Edison Illuminating Company of Boston, and they really could have saved a great deal of money if they had just taken part of what they had and thrown it into Boston Bay and saved the

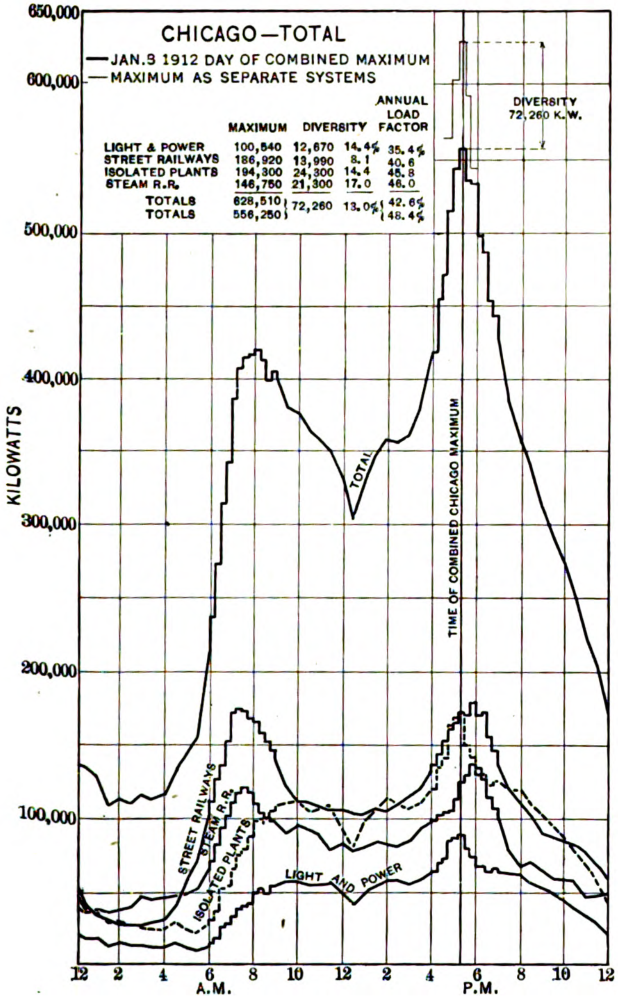


FIG. 6

balance by contracting with the Edison Company of Boston for service.

Fig. 6 shows the total load diagram for Chicago. The diversity shown in the tabulation on this chart amounts to 72,260

kw., and would require, assuming a 25 per cent reserve, 90,300 kw. more capacity if operated as separate systems than if operated on a combined generating system. At $75 per kw. this amounts to an extra investment of $6,772,500.

The isolated plant load, although showing a maximum 50 per cent greater than our present light and power load, I believe has been estimated conservatively low. A canvass of the number and size of isolated plants was made by the contract department of the Commonwealth Edison Company, and several checks on these figures were available, such as "The Engineers' Directory," the agents' knowledge of the field and the City of Chicago Boiler Inspectors' records.

In estimating this isolated plant load, the separate maxima of the plants are assumed to be two-thirds of the rated capacity, and the load factor, that is, the ratio of the average kilowatts for the year to the maximum kilowatts, is assumed to be 25 per cent, the assumption being based on the fact that the actual load factor of customers on our wholesale schedule, representing a very large amount of business, is 26 per cent.

On account of the diversity between the different isolated plants, it is assumed that their load factor, if combined, would be equal to the load factor of the Commonwealth Edison Company's general light and power business, that is, 35.5 per cent.

To the maximum kilowatts and kilowatt-hours thus obtained are added a certain portion of the South Chicago Steel Works load, the refrigeration load, assuming that one-half the ice of Chicago is produced electrically, and the electric vehicle load, assuming two-thirds of all horses replaced by electric vehicles. These latter two items, being off-peak loads, improve the load factor up to the figure shown, although they represent only 17 per cent of the total estimated kilowatt-hours of the isolated plants.

The increased investment necessary as between these systems being operated all as one, including steam railways, and being operated as separate systems, taking the cost of generating plant plus the cost of the primary transmission system, would mean an expenditure of upwards of $10,000,000 to $12,000,000 more than if the work is done on one system. We have got reasonably well started in Chicago towards doing it on one system. We have practically the most important part of the work, that is, the street railway work, and we are trying there to do all we can to get the isolated plants out of existence, and in the steam

railroad business, as may be seen from our estimates, in what is the greatest railroad center in the United States to-day, passenger, freight and transfer business combined, the amount of energy required for operating all of the terminal systems there is so small a percentage of the whole that it would seem unreasonable to think we will not be able to get that, certainly in Chicago, as well as the business of the surface and elevated railroads.

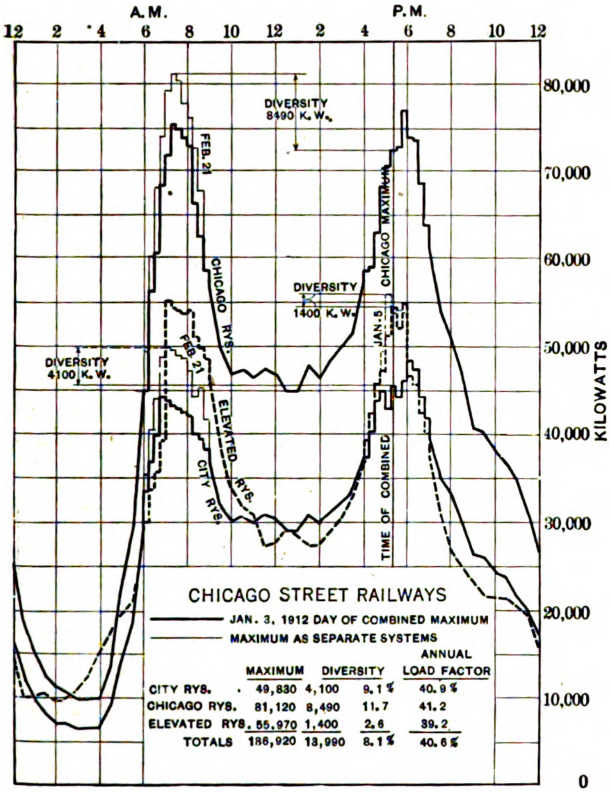


Fig. 7

The next diagram, Fig. 7, shows the load curve of the street railways of the city of Chicago. One interesting feature of this chart is that the highest maximum for two of the street railway companies occurred in the morning of February 21st, soon after the beginning of a very heavy snow storm, with a strong cold wind blowing and the temperature a little above 20 deg. fahr.

That chart is generally characteristic of the urban transportation business of a city of the size of Chicago.

Fig. 8 shows the load diagram of the electrified steam railroads of Chicago, assuming that the steam railroads in the vicinity of Chicago are electrified some time. It is a load diagram of the maximum for the year. The method of estimating all of the data regarding the load of the electrified steam roads of Chicago is given in detail in the appendix to this paper, on "Electric

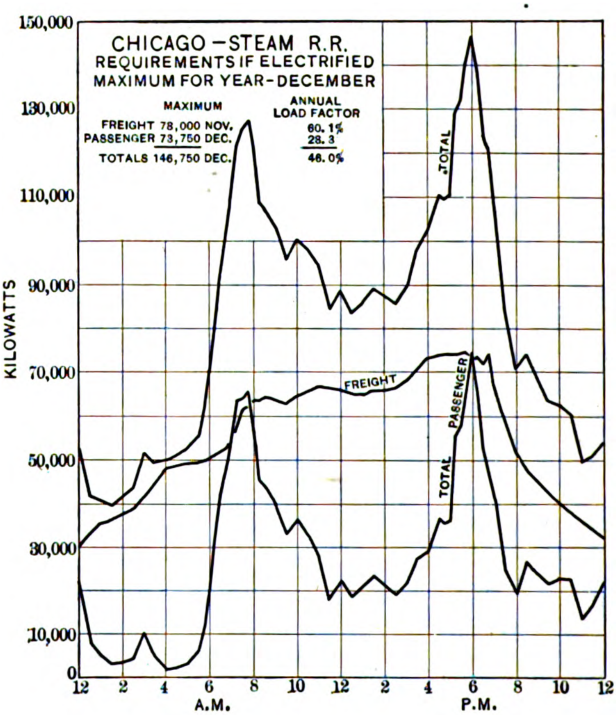


FIG. 8

Power Requirements of the Electrified Steam Railroads of Chicago," prepared by Messrs. Bird, Gear and Fowler.

The freight curve, you will see, has an extremely good load factor. The passenger business is governed by exactly the same conditions, only intensified, that govern the passenger business in New York City. I presume the curves of passenger business in New York, Chicago, Boston and Philadelphia would probably be all about the same, except that Philadelphia, Boston and New

York ought to have some advantage from a much larger amount of pleasure business in the summer than we get in Chicago.

The extreme peak in the morning and evening is caused by the suburban business, the extra amount of energy necessary at the time of extreme cold for traction purposes and the extra amount of energy necessary for heating purposes. If it were not for these two peaks, the load factor would even up better than it does, and yet, notwithstanding these peaks, the combined freight and passenger business is estimated to have 46 per cent load factor. Now, if we consider the steam railroad business, say in cities of the size of Rochester, Detroit, Buffalo, and possibly

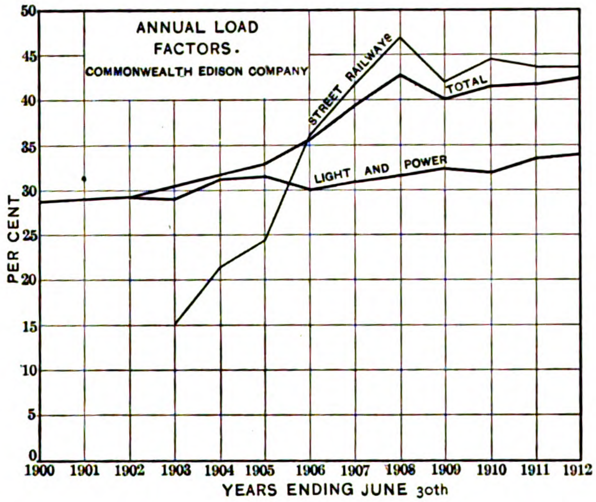


FIG. 9

Cleveland, Toledo, and similar cities, their load factors would be uniformly better than is shown in Fig. 8, and in my judgment the date of the maximum load, and the time of day of the maximum load, would probably change considerably, to the advantage of the local power company supplying the energy.

I thought it might be of interest to include a chart of the annual load factors of the Commonwealth Edison Company for the last twelve years, as shown in Fig. 9. You will notice that the street railroad load factor went up and then dropped. It was at its highest for a few years just before one of the large street railways shut down its obsolete stations, which it had operated as peak plants only, also having the result of earning it

a very low price for the energy it purchased. The tendency of the railway load factor is to run even. The tendency of the light and power load factor is to run up. The combined load factor, as shown in Fig. 9, is about 42.5. The light and power business by itself has a load factor a little under 35, and the street railway business by itself about 43 per cent.

Fig. 10 shows the diversity in a block of apartments. This figure has been used a number of times, both by myself and by some of my subordinates in writing papers on different subjects where the question of diversity and load factor comes in, for it is a striking illustration of diversity. The figure shows a block composed of average apartments, all alike. The number of apart-

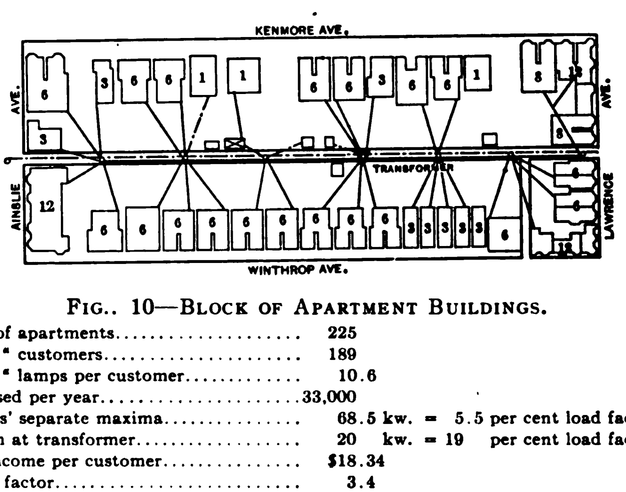


FIG.. 10—BLOCK OF APARTMENT BUILDINGS.

Number of apartments	225	
" " customers	189	
" " lamps per customer	10.6	
Kw-hr. used per year	33,000	
Customers' separate maxima	68.5 kw.	= 5.5 per cent load factor
Maximum at transformer	20 kw.	= 19 per cent load factor
Annual income per customer	$18.34	
Diversity factor	3.4	

ments is 225, number of customers 189, lamps per customer 10.6, the kilowatt-hours used per year 33,000, and the customers' separate maxima show only 5.5 per cent load factor. The maximum at the transformer shows 19 per cent load factor. Here are 189 customers, all living in similar apartments, all of about the same class, all with about the same habits of life, and yet the difference in the load factor, taking each customer by himself, as compared with all of them put together, is such that you get almost four times as good a load factor, and that is owing to the diversity of demand. That is the fundamental basis of the profit-making of an energy selling company. We get that average in dealing with small customers, and consequently we can sell these small customers at a profit as a whole, whereas

any engineer who knew the facts could demonstrate to me that each one by himself is a loss to us.

It is exactly that same principle—I am getting down to the fundamentals, the A, B, C, of energy production and distribution —that I and others who advocate the same ideas want to see

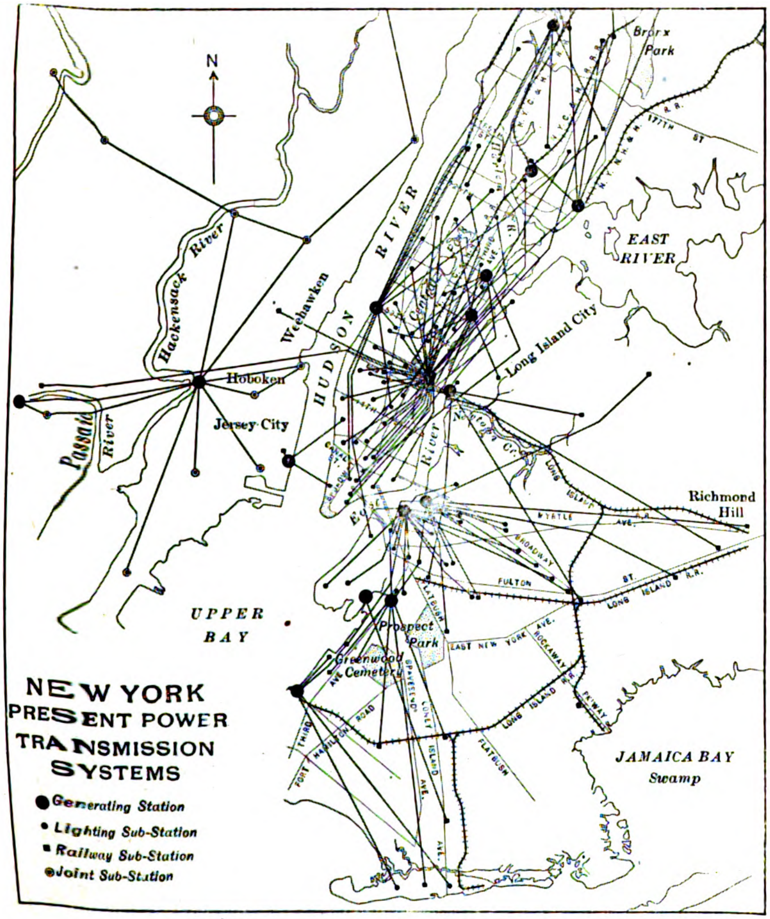


FIG. 11

applied in all the electric supply business, whether it is in large communities or small communities; and I want to see somebody get the advantage of that diversity factor that exists. In one case, with small customers, it may show 400 per cent advantage. In another case, in a vast community like the

city of New York and surrounding territory, that percentage may be only ten per cent, but it runs up into millions and millions of dollars, which is being thrown away to-day, and I do not want to see those who are right on the threshold of entering into our line of business, the use of electrical energy, make mistakes

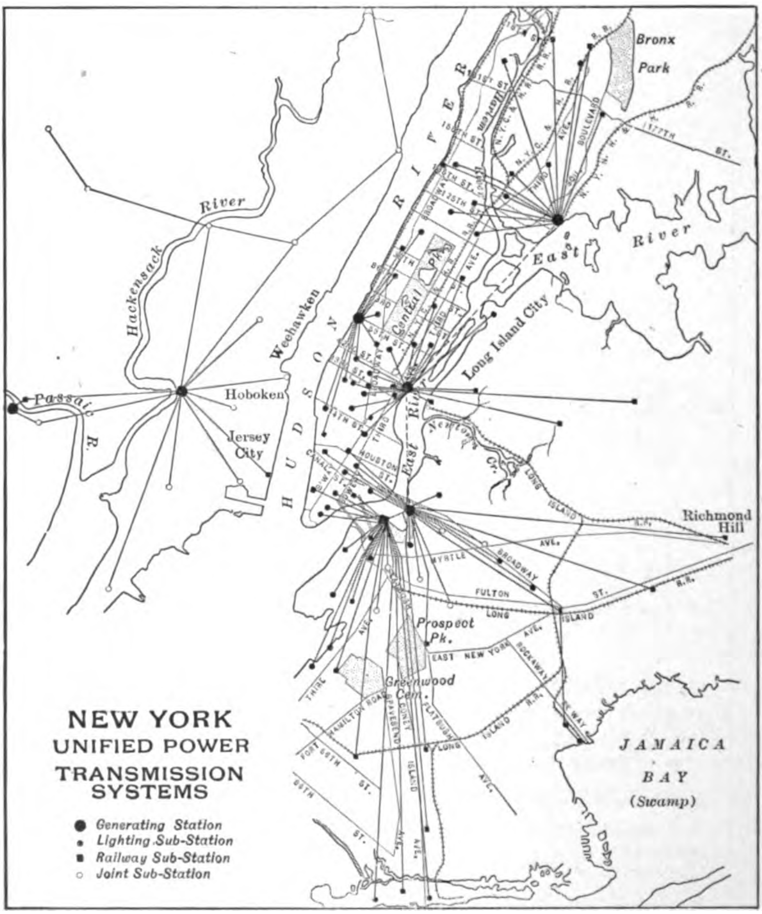


FIG. 12

owing to their ignorance of the real situation. I do not want to see them make the mistake that, in my judgment, largely through force of circumstances, the New York Central company has made in building its present power house, and the Pennsylvania Railroad Company has made in building its power house,

probably, I think, as much because they could not find people to sell them energy as because they did not know they ought to buy energy instead of manufacturing it.

Fig. 11 is a map of New York City, with the present power transmission systems. In referring to New York City, you will notice that I go out on the Hackensack river into New Jersey,

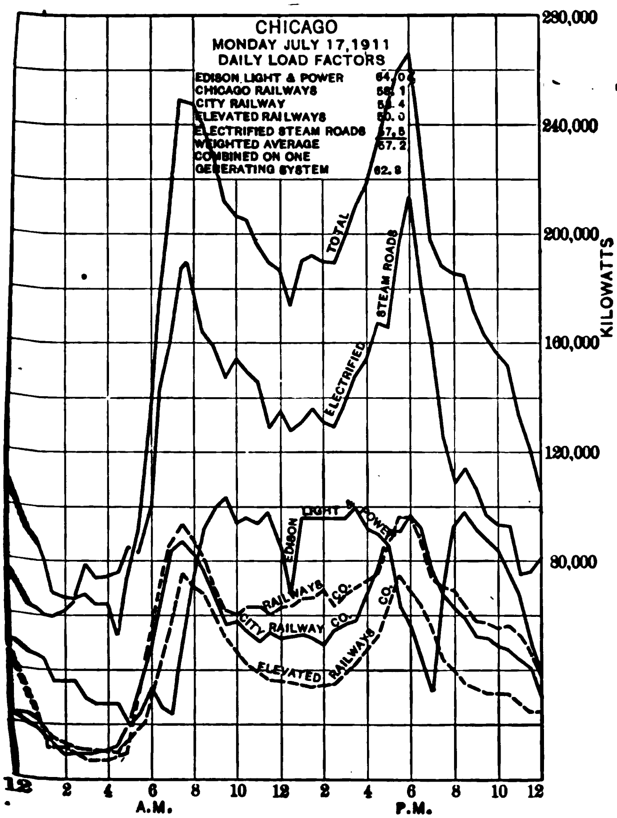


FIG. 13

as I consider that territory properly a part of the area included in the greater city for the purposes of the present discussion.

Fig. 12 shows the New York power transmission system unified into one system. You will notice the difference between the two. In Fig. 11 the vast number of substations and transmission lines is in marked contrast to the effective distribution in Fig. 12.

Fig. 13 shows the Chicago daily load factor. This diagram

shows the improvement in load factor as it affects operating conditions, the improvement being due mainly to the railway load coming up earlier in the morning and the depression in the light and power load at the time of the evening railway peak. It is almost impossible to figure absolutely and closely this saving from concentration of production of electric energy. It is easy enough to figure the saving of investment, but it is pretty hard to figure the saving in operating expense. It is a very large amount, indeed, and the items especially affected are the items of what one might call " readiness to serve ", including, of course, the expenses incident thereto. I do not refer to fixed charges but to operating expenses outside of fixed charges. Although it is easy to figure the saving in fixed charges due to diversity, it is not so easy to figure the saving due to the broadening out of this daily curve, but it goes a long way towards reducing the readiness-to-serve charges per unit produced in a given time.

In Table I is a tabulation of the daily load factors in Chicago. This expresses the matter a little differently. The average daily or operating load factors for the different systems operating separately, 55.6 per cent, is equivalent to thirteen and one-half hours straight-line or steady operation per day. The load factor for all combined on one generating system, 59.9 per cent, is equivalent to fourteen and one-half hours per day, or an increase of one hour, or 7.4 per cent. This improvement means that the fixed charge and " readiness-to-serve " portion of the operating expense is prorated over a greater number of units of output per day and per year.

You will notice, as shown in the table, the improvement in conditions in each month in the year. The average shows a decided improvement if the systems are combined in one. The average is 59.9 and the average of the others, separately, is 55.6 per cent.

Fig. 14 shows a diagram of the Boston daily load, and Table II is a tabulation of the Boston daily load factors. It shows that there would be quite an improvement if the Boston Elevated and the Boston Edison loads were operated together. The average is 53.9 per cent operated separately and 59.4 per cent if operated as one system.

Table III gives a tabulation of the New York daily load factors. It gives the same general character of information. Operated separately the stations show 51 per cent, and operated together 56.2 per cent.

TABLE I—CHICAGO
DAILY LOAD FACTORS

	1911 Mon. Feb. 13	Wed. Mar. 15	Sat. Apr. 15	Tue. May 16	Fri. June 16	Mon. July 17	Thur. Aug. 17	Sun. Sept. 17	Fri. Oct. 20	Mon. Nov. 20	Thur. Dec. 28	1912 Wed. Jan. 3	Average of 12 months
Commonwealth Edison Light and Power	62.4	63.5	54.5	56.3	64.2	64	56.5	42.5	50.9	51.4	49.3	49.4	55.4
Railways Company	58.3	54.5	58.2	54.3	53.3	58.1	52.6	61.1	53.7	52.8	53.5	56.5	55.6
City Railway Company	57.5	52.4	55.3	49.8	48.4	53.4	49.1	66.9	51.5	61.1	60.2	57.6	55.3
Elevated Railway Company	51.5	49.8	50.7	49.9	48.5	50.3	48.8	66.3	45.7	48.3	55.7	51.7	51.4
Electrified steam railroads	55.5	55.5	57	58.7	58.8	57.5	59.3	64.8	60.2	58.4	55.7	54.8	58
Weighted average of above	56.5	55.5	55.8	55.3	56	57.2	55	58.7	54.3	54.8	54.5	53.8	55.6
Combined on one generating system	60.7	59.1	64.3	57.6	62.2	62.8	59.8	61.5	56.4	58.3	58.6	57	59.9

TABLE II—BOSTON
DAILY LOAD FACTORS

	1911 Mon. Feb. 13	Wed. Mar. 15	Sat. Apr. 15	Tue. May 16	Fri. June 16	Mon. July 17	Thur. Aug. 17	Sun. Sept. 17	Fri. Oct. 20	Mon. Nov. 20	Fri. Dec. 22	1912 Fri. Jan. 12	Average of 12 months
Boston Edison	59.2	68.2	59.6	63.9	65.7	69.5	68.8	47.4	52.5	42.6	44.2	52.8	57.9
Boston Elevated	51.3	52.8	56.2	48.8	51.9	48.1	49.3	70	45.9	48.4	52.7	53.3	52.4
Weighted average of above	54.5	58.6	57.5	54.6	57.2	55.5	56.7	56.2	49.5	45.6	48.4	53.1	53.9
Combined on one generating system	54.8	62.7	63.2	66.4	67.3	63.4	66.3	56.2	49.5	51.6	55	56.1	59.4

TABLE III—NEW YORK
DAILY LOAD FACTORS

	1911 Mon. Feb. 13	Wed. Mar. 15	Sat. Apr. 15	Tue. May 16	Fri. June 16	Mon. July 17	Thur. Aug. 17	Sun. Sept. 17	Fri. Oct. 20	Mon. Nov. 20	Thur. Dec. 21	1912 Sat. Jan. 13	Average of 12 months
New York Central.........	48.0	47.4	46.8	43.2	45.6	43.9	44.3	63	40.5	43.3	45.7	44	46.3
New York, New Haven & Hartford..............	52.4	49.8	56.2	50.9	49.5	47.2	51 2	50.1	50.3	48	48.8	53.2	50.1
Pennsylvania R. R.........	58.4	54.4	57.8	49.3	51.6	49.9	47.3	64.8	54.3	49.1	49.9	53.3	53.2
New York Edison Co......	52.1	57.6	52.8	57.2	58.5	62.2	61.7	46.8	48	42.3	44	45.7	52.4
Brooklyn Edison Co.	49.6	50.7	44.4	46.9	45.3	45.7	48	43.6	51.2	52.2	48.5	49.1	47.9
Public Service Co. (Light and power)...........	50.5	47	40	46	42.6	46.2	47.3	39.5	46.8	43.5	45.3	48.8	44.9
Public Service Co. (railway)	50.7	47	61.3	45.6	42.2	46.9	49.1	64.	50	47.4	47.3	49	50
Brooklyn Rapid Transit.....	59.7	50.6	57	48.8	48.4	52.8	49.1	66.1	45.6	48.5	50.6	46.3	52
Interborough Rapid Transit	64.2	49.8	53.3	48.1	49.6	57.5	58.5	57.8	58.5	58.5	53.5	51.5	55.1
Third Ave. R. R...........	70.6	54.7	58.5	52.8	54.5	63.3	64.3	63.5	64.3	64.3	59.1	56.6	60.5
Hudson & Manhattan.....	54.1	46.1	46.5	46.6	49.3	45.9	46.7	71.3	49.2	49	55.2	47.4	58.9
Weighted average of above.	53.4	52.8	52.7	50.7	50.3	52.2	52	54	49.5	48.1	48	48.4	51
Combined on one generating system...............	53.6	54.6	64.4	58.7	58.7	60.7	59.4	63.8	49.6	50.2	50.6	50.1	56.2

Fig. 15 is a comparison of the Chicago and New York load diagrams. In this diagram the different load curves shown have all been prorated so that the maxima of all are equal and the same as that for Chicago for January 3, 1912. This method of comparing load diagrams shows just what hours of the day are affected by the improvement in load factor, and brings out

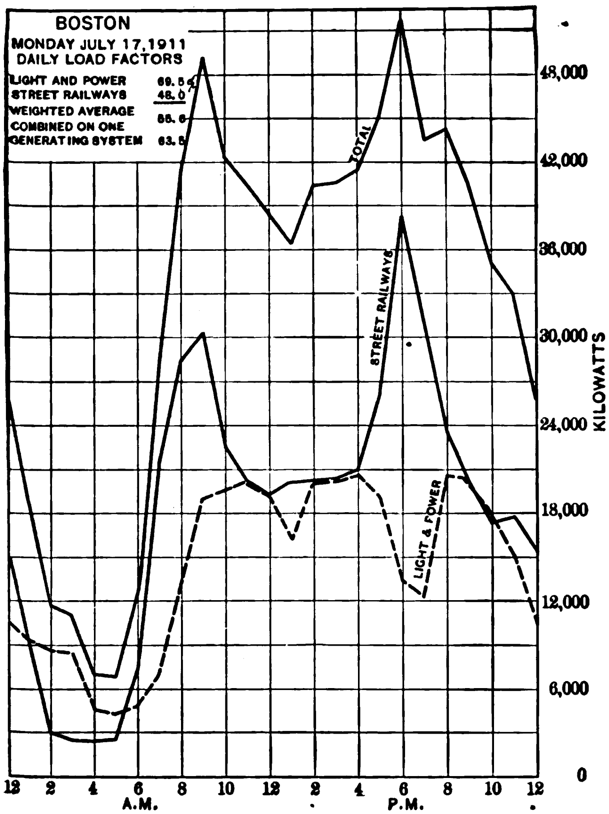


FIG. 14

perhaps more clearly than any other method the great advantage from an operating standpoint of the combination of the energy supplied for different purposes on one generating system. This improvement, for instance, for Chicago as compared with New York, has a very decided effect upon the operating cost, and is one of the principal reasons for the very low generating cost in Chicago.

The effect of diversity on the peak, which results in a saving in investment, can be and has been very readily figured. But the effect of this diversity in reducing the operating cost cannot be so readily calculated. Nevertheless, there is no doubt that the saving in operating expense is fully as important as the saving in investment.

Fig. 15 was prepared to show exactly the result of the policy the Commonwealth Edison Company has pursued in Chicago for the last ten years. It was just about ten years ago when we

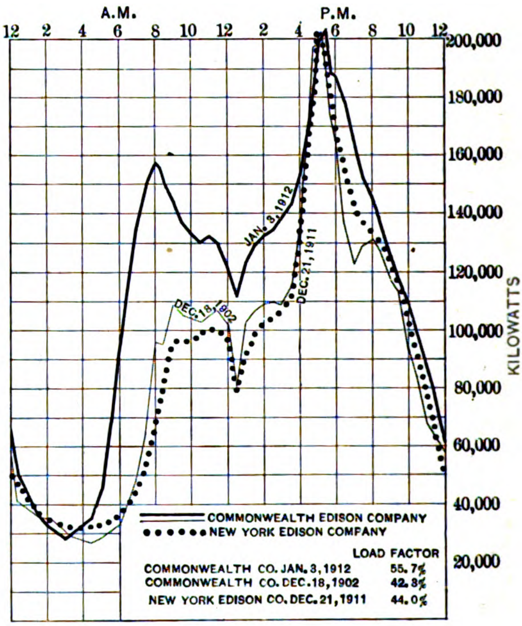


FIG. 15.—NEW YORK AND CHICAGO—LOAD DIAGRAMS FOR MAXIMUM DAY OF YEAR PRORATED TO CHICAGO 1912 MAXIMUM FOR COMPARISON.

commenced to sell energy at prices that most of the producers of energy in this country thought were so ridiculously low that it was only a question of time and the size of our pocket-book as to how long we could stand it. This diagram shows you the result we have been able to obtain. As a contribution to our fixed charges, as a contribution to our stand-by charges, as a means of producing more kilowatt-hours in a given period, so as to provide us with the necessary funds to adopt a reasonably bold policy of selling energy, in ten years we have been able to attain this result.

Fig. 16 is a comparison of the Chicago and Boston load diagrams.

Fig. 17 is a map showing the Chicago railroad terminals in the proposed electrical zone, the boundary of which was laid out by the Chicago Association of Commerce. The zone includes a territory about 32 miles long, with an average width of ten to twelve miles.

Fig. 18 is a map of the electrification of steam railroads in Chicago,—based on a plan of group operation: that is, a plan of

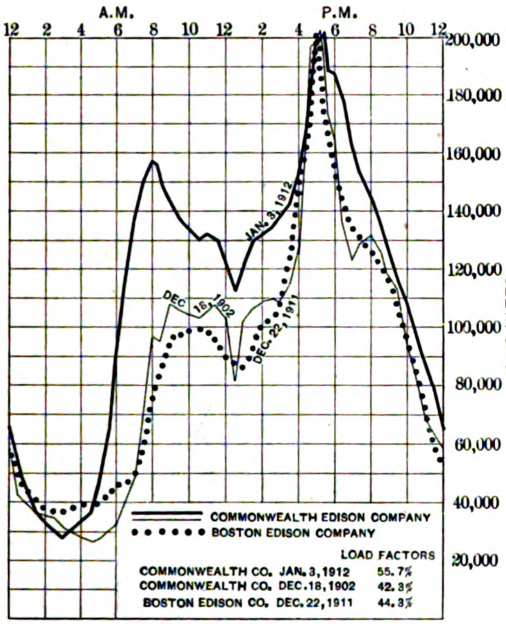


Fig. 16.—Boston and Chicago—Load Diagrams for Maximum Day of Year Prorated to Chicago 1912 Maximum for Comparison.

generating stations, substations and primary transmission lines on the theory that the railroads of the various financial groups, the New York Central group, the Pennsylvania group, and so on, would operate their power jointly, *i.e.*, that the New York Central would have a system for itself, the Pennsylvania would have a system for itself, and so on all the way down the line.

Fig. 19 shows the electrification of steam railroads, with unified power supply, in the city of Chicago. That is what it would be like if all the companies obtained their power from


CHICAGO
RAILROADS TERMINALS
IN PROPOSED
ELECTRICAL ZONE
Passenger Terminal
Freight Yard
N
LAKE MICHIGAN
Glencoe
Evanston
Galewood
Riverside
Clearing Yards
Englewood
Stony Island Ave.
S. Chicago
Whiting
Indiana Harbor
Blue Island
Burnham
West Hammond
ILLINOIS-INDIANA STATE LINE

FIG. 17


CHICAGO
ELECTRIFICATION
OF
STEAM RAILROADS
GROUP OPERATION
Generating Station
N
LAKE MICHIGAN
Glencoe
Evanston
Galewood
Riverside
Clearing Yards
Englewood
So. Chicago
Whiting
Indiana Harbor
Blue Island
Burnham
West Hammond
ILLINOIS-INDIANA STATE LINE
WABASH
GRAND TRUNK
TRUNK

FIG. 18

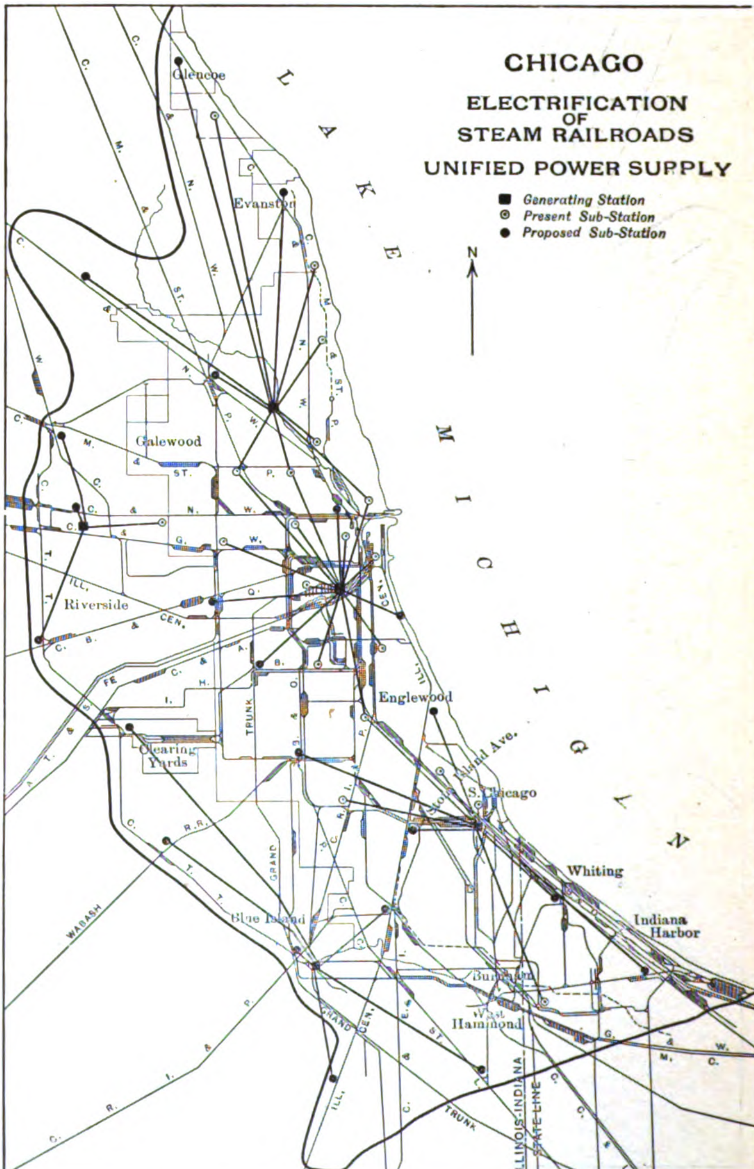

CHICAGO
ELECTRIFICATION
OF
STEAM RAILROADS
UNIFIED POWER SUPPLY
Generating Station
Present Sub-Station
Proposed Sub-Station
N
LAKE MICHIGAN
Glencoe
Evanston
Galewood
Riverside
Englewood
Clearing Yards
S. Chicago
Whiting
Indiana Harbor
Blue Island
West Hammond
WABASH
ILLINOIS-INDIANA STATE LINE

FIG 19

one source, and shows the difference between purchased power and individual production.

Fig. 20 is the load diagram of the freight electrical requirements of the steam railroads in Chicago. This is a curve we have had worked out in relation to freight business, and it shows some rather interesting things. This freight curve has an extremely good load factor, estimated at 70 per cent daily and 60 per cent yearly. Through freights come in during the early morning hours and are broken up, switched and transferred from

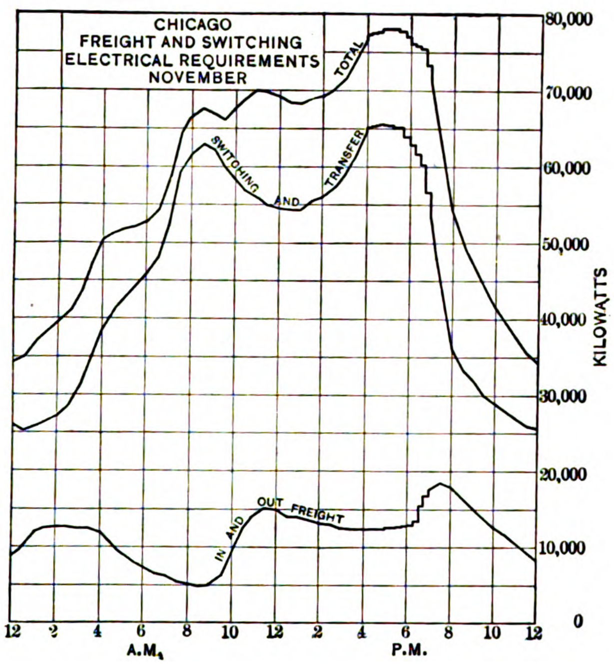


FIG. 20

7 o'clock in the morning on, and then during the late afternoon there is another switching and transfer peak caused by the making up of the through freights and getting them ready to go out as soon as the late afternoon passenger peak is over. The peak on the in and out freight of the day occurs from 7 o'clock in the evening on, due to these outgoing through freights which were made up in the late afternoon.

Fig. 21 is the diagram of the freight earnings and monthly freight electrical requirements of the roads in Chicago. It shows

the monthly gross freight earnings for two years for a group of Chicago roads, and also for the Elgin, Joliet & Eastern, which latter ought to show whether local Chicago conditions vary materially from the curve for the trunk lines included, as it has been impossible to get, in any way, the figures of local earnings of the different trunk railroads.

It has been assumed that normal electrical requirements of freight traffic will vary for the different months of the year similarly to the variation shown for the twelve roads for 1910 and 1911, and that these normal requirements will be increased during the winter months as shown, on account of increased traction or increased resistance due to the cold.

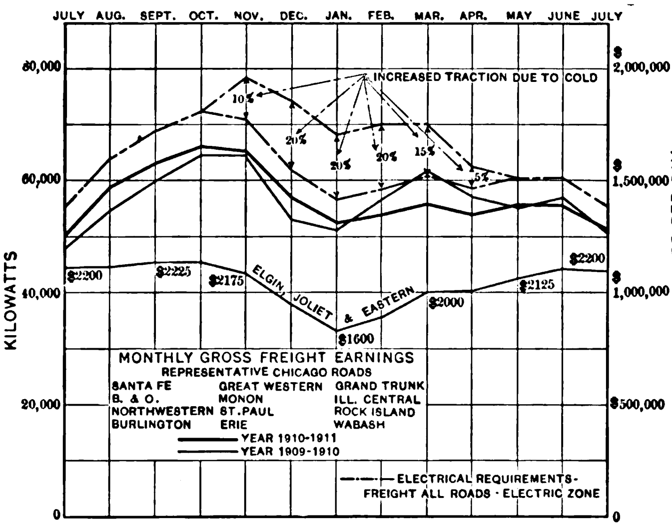


FIG. 21

Fig. 22 is the load diagram of the steam railroad passenger electrical requirements in Chicago. This diagram shows these requirements in December. It has the same general characteristics as the New York curve, with the high peak morning and evening, owing to the suburban passenger business and owing to the heating of the cars.

Fig. 23 shows the passenger earnings and monthly electrical requirements in Chicago, the latter being based on an assumed variation one-half that of the earnings for 1910–11. This diagram assumes, for through passenger business, that the cars

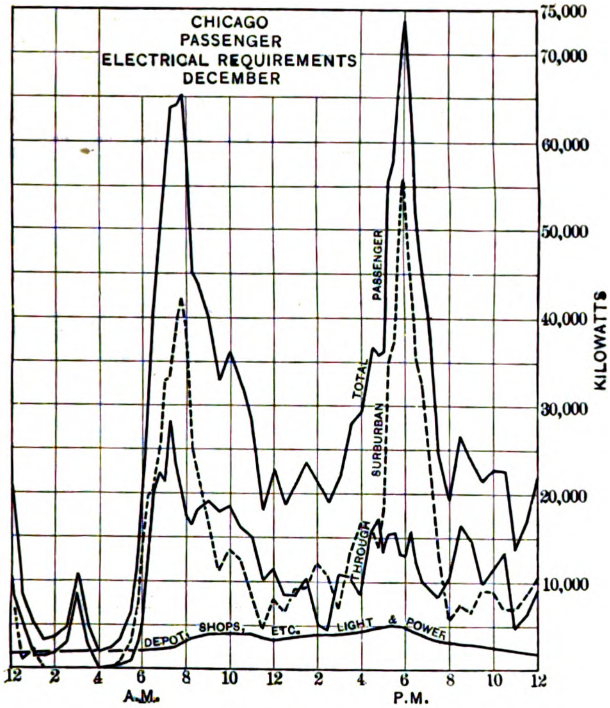

CHICAGO
PASSENGER
ELECTRICAL REQUIREMENTS
DECEMBER
75,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
KILOWATTS
TOTAL
PASSENGER
SURBURBAN
THROUGH
DEPOT, SHOPS, ETC., LIGHT & POWER
12 2 4 6 8 10 12 2 4 6 8 10 12
A.M.
P.M.

FIG. 22

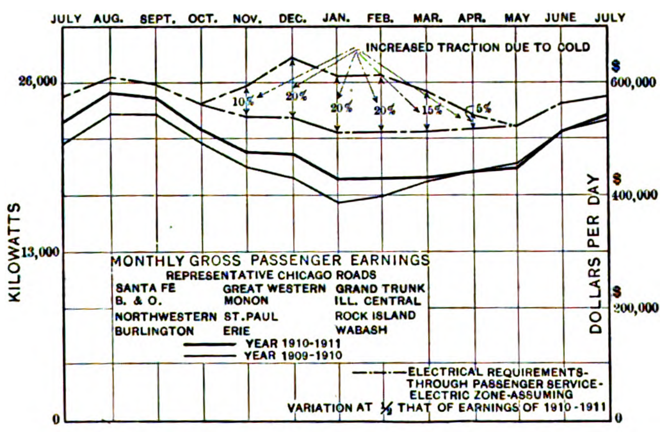

JULY AUG. SEPT. OCT. NOV. DEC. JAN. FEB. MAR. APR. MAY JUNE JULY
INCREASED TRACTION DUE TO COLD
10% 20% 20% 20% 15% 5%
26,000
13,000
0
KILOWATTS
$ 600,000
$ 400,000
$ 200,000
0
DOLLARS PER DAY
MONTHLY GROSS PASSENGER EARNINGS
REPRESENTATIVE CHICAGO ROADS
SANTA FE
B. & O.
NORTHWESTERN
BURLINGTON
GREAT WESTERN
MONON
ST. PAUL
ERIE
GRAND TRUNK
ILL. CENTRAL
ROCK ISLAND
WABASH
YEAR 1910-1911
YEAR 1909-1910
ELECTRICAL REQUIREMENTS-THROUGH PASSENGER SERVICE-ELECTRIC ZONE-ASSUMING VARIATION AT ½ THAT OF EARNINGS OF 1910-1911

FIG. 23

will be heated by steam, and you will notice the increased energy which is required for traction owing to the cold.

Fig. 24 shows the proposed steam railroad suburban electrical requirements, month by month, in Chicago. In addition to the

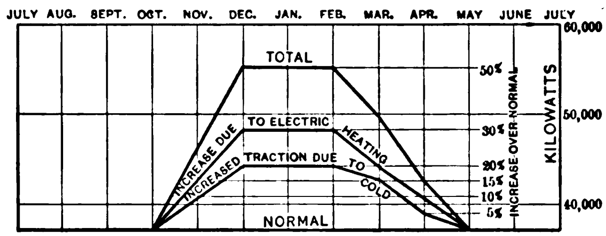


FIG. 24.—ELECTRICAL REQUIREMENTS, STEAM RAILROAD SUBURBAN SERVICE—CHICAGO ELECTRIC ZONE.

normal amount of energy required, there is the increased requirement for traction due to cold, and the increase due to electric heating.

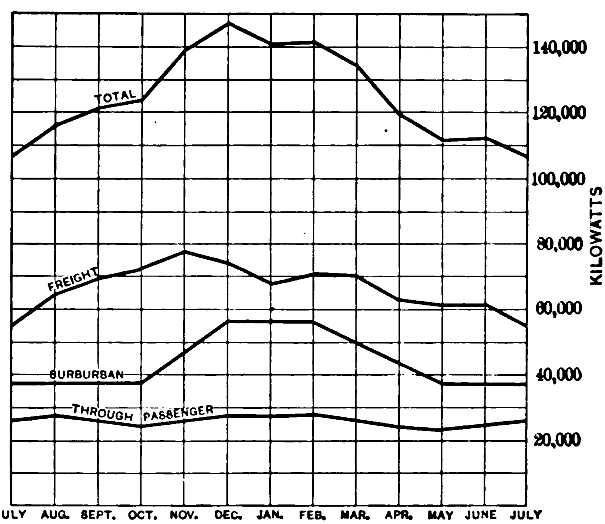


FIG. 25.—MONTHLY VARIATION IN MAXIMUM ELECTRICAL REQUIREMENTS —STEAM RAILROADS IN CHICAGO ELECTRIC ZONE.

Fig. 25 shows the monthly variation in the total electrical requirements in the proposed electrification of the Chicago steam railroads. You will remember that the load factor of

the through passenger business is extremely good, and of the freight business extremely good. That would indicate, except in the ten or twelve large cities to which I have referred, that the freight and passenger business ought to be very good throughout the country.

Fig. 26 gives a comparison between the swing maximum and the one-hour maximum load on the New York, New Haven & Hartford Railroad Company's Cos Cob station. This diagram of the New Haven road is important because it shows that small roads, installing their own plants, must provide a capacity sufficient to cover the maximum swing, which frequently lasts several

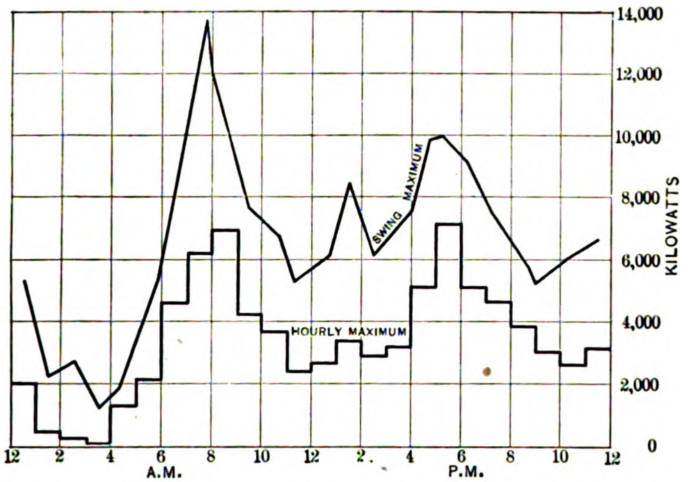


FIG. 26.—DIAGRAM SHOWING RELATION OF SWING MAXIMUM TO ONE-HOUR MAXIMUM, N. Y., N. H. & H. R.R.—COS COB STATION, JULY 17, 1911.

minutes, and which, in the case of the New Haven road, apparently necessitates a reserve amounting to 74 per cent.

The three-phase capacity of their generators is 21,000 kw. and their maximum load is 9050 kw., which is a reserve of 132 per cent. But their single-phase operation really reduces the actual capacity of the generators, on a single-phase basis, to 15,000 kw., which is equivalent to 74 per cent reserve. They apparently have no greater reserve than is necessary, because they are installing three 6000-kw. three-phase units for additional capacity to take care of additional electrification. In another part of the paper, for the purpose of figuring the capacity of the steam plants if each of the roads installed its own plant, instead

of using this actual 74 per cent reserve, we have assumed 50 per cent, to be conservative, as compared with 25 per cent reserve in case of purchase of energy.

The point brought out in this curve is also important from an operating standpoint, because, with a system of central stations for all energy used in a community, the entire load factor would be in the neighborhood of 60 per cent, as shown in Table I, compared with 25 per cent for this diagram using the maximum swing.

I would like to say just a little, before I conclude, with relation to the actual saving that, in my judgment, could be obtained, assuming that an effort were made to bring about the concentration of production and the concentration of primary distribution system in the area of greater Greater New York, that is, an area including the Jersey shore a little beyond the Hackensack river. The total saving in investment that could be worked out over a period of relatively few years, based on the experience that we have had in Chicago, would amount to about $18,000,000 to $20,000,000. That is in investment alone. The saving in operating expenses would amount to about $1,000,000 a year. Now, figuring fixed charges of 5 per cent for depreciation and 5 per cent for interest on the saving in investment, and adding to that the saving in operating expense, you have a sum almost equal to $3,000,000. That sum, capitalized at 5 per cent, means a creation of $60,000,000 of value.

At the rate of progress now going on in the neighborhood of New York the business is bound to double inside of ten years. If the present scheme is followed out,—if the traction companies have their own separate sources of supply, if the electric light and power companies have their own separate sources of supply, if the steam railroads that are apparently on the threshhold of electrification have their own sources of supply,—at the end of ten years, the waste in money which will have taken place, on a 5 per cent basis, will be somewhere between $140,000,000 and $175,000,000. The direct saving by a concentrated system of generation and primary distribution, leaving out of consideration altogether the saving in operating expenses, is of itself, in my opinion, sufficient to provide the necessary funds for that portion of steam railroad electrification centering in New York. That is, assuming the steam railroad requirements as about 170,000 kw., I do not believe that the portion of combined generating stations and combined primary distribution system for that purpose would cost much over $100 to $110 a kilowatt, taking it on the basis of a combined system.

The figures which my engineers have prepared indicate that if there should be made a systematic effort at massing production and massing primary distribution in the area referred to, the amount of property that would be realized or made available for increased business would be worth $18,000,000, or thereabout. I do not think that the power necessary for the steam railroads centering in New York, and the primary system necessary to take that current to the railroads, would cost over $18,000,000.

Now the savings are here at your feet. The engineering representatives of the interests that have these various public services in charge are most of them members of the Institute, and they can check up the figures. I will not attempt to burden the Institute records with the details, but they are at the disposal of anybody who wants to use them. I am speaking not from any theoretical point of view, but from my own knowledge and experience in developing the business which it is my pride to preside over;—I know that the change that I have been able to work there, from barely earning dividends to putting the property in a strong, conservative position, has been the result of following the policy that I have laid down here, and I urge the people who are interested to try to follow it out round New York. It is a policy that is worthy of the greatest engineers and worthy of the thought of the greatest financiers in this country. It is a conservation of the truest order. If the same policy is carried out throughout the United States, the conservation of fuel alone will be something tremendous. The conservation of labor will be something tremendous. The letting loose of capital that can be used in other directions will stimulate business.

There is no greater problem in the industrial world today, no problem that presents greater opportunities for the engineers to achieve distinction, no problem that presents greater opportunities for the financier to achieve distinction and profit, than the proper method of producing energy and distributing it in a given area, and involved in that question is the solution of providing money for that portion of the electrification of steam railroads that ends when the energy is put into the track.

Before concluding, I think it is but fair to my own staff that I should say that it would have been impossible for me to present this paper if it had not been for the loyal and valued assistance rendered me for three months in preparing data for this discussion, under the direction of Mr. Junkersfeld, of the

Commonwealth Edison Company, and the close personal work of Mr. Fowler, our Chief Statistician, Mr. Gear, our Engineer of Distribution, and Mr. Bird, one of the engineers of our Contract Department. These gentlemen whom I have mentioned have worked so hard on this matter, and given so much of their time to it, that it is only due to them that I should make this statement.

APPENDIX

Electric Power Requirements of Chicago Steam Railroads Electrified—1911-1912

PREPARED BY PAUL BIRD, H. P. GEAR AND E. J. FOWLER

ELECTRICAL REQUIREMENTS OF FREIGHT SERVICE ON ELECTRIFIED STEAM RAILROADS IN CHICAGO DISTRICT—COMPUTATIONS MADE IN MARCH, 1912

The electrical requirements of the freight service of Chicago have been worked out for the same zone that is being considered by the Association of Commerce Committee on Smoke Abatement and Electrification of Railway Terminals.

The computations cover the year from July, 1911 to June, 1912, and it is assumed that the steam railroads in this district are electrified with no changes in the tracks and yards, and that freight is handled through the city in the same manner and following the same routes as it does today.

When the railroads are actually electrified there is no question but that great changes will be made in the freight terminals, and that a large part of the freight that now comes through the heart of the city will pass around and outside the city limits and possibly outside the electrified zone.

The results of the investigation are:

Month	Maximum demand	Kw-hr.	Load factor Per cent
July, 1911	55,200	28,814,400	70.3
August	63,800	33,303,600	69.6
September	68,700	34,624,800	70.3
October	72,100	37,636,200	70.2
November	78,000	39,312,000	70
December	74,200	38,732,400	70.3
January, 1912	68,200	35,600,400	70.3
February	70,200	32,853,600	69.7
March	70,000	36,540,000	70.3
April	62,500	31,500,000	70.1
May	60,400	31,528,800	70.2
June	60,300	30,391,000	70
		410,837,200	

The maximum demands and the consumption for December, the month during which the railway maximum demand would occur, are as follows:

DECEMBER FREIGHT REQUIREMENTS

Railroads	Maximum Demand	Kw-hr.
Wabash R.R.	1611	840,900
C. I. & L. R.R. (Monon)	736	384,200
L. S. & M. S. Ry.	3244	1,693,400
N. Y. C. & St. L. R.R. (Nickel plate)	1033	539,200
P. Ft. W. & C. Ry.	3352	1,749,700
B. & O. R.R.	1713	894,200
M. C. R.R.	2878	1,502,300
Erie R.R.	1680	877,000
P. C. C. & St. L. R.R.	2091	1,091,500
Chicago Great Western Ry.	1124	586,700
Northwestern Ry.	7605	3,969,800
Rock Island Ry.	2520	1,315,400
C. B. & Q. R.R.	5098	2,661,200
St. Paul R.R.	4127	2,154,300
Ills. Central R.R.	4377	2,284,800
Santa Fe R.R.	913	476,600
C. & A. Ry.	1572	820,600
C. & E. I. R.R.	3193	1,666,700
Grand Trunk R.R.	1201	626,900
Wisc. Central (M. S. P. & S. S. M.)	1256	655,600
C. & O. of Indiana	110	57,400
Chicago & Indiana Southern	148	77,300
Pere Marquette	368	192,100
Chicago & Western Indiana	967	504,800
B. & O.—C. T. R.R.	2390	1,247,600
C. Junction R.R.	4682	2,444,000
E. J. & E. Ry. (C. L. S. & E. R.R.)	3845	2,007,100
Belt Ry.	7071	3,691,100
Chicago, West Pullman & Southern Ry.	710	370,600
Ills. Northern	423	220,800
Manufacturers Junction	171	89,300
Misc. Belt Roads	1991	1,039,300
Total	74,200	38,732,400

Methods and Data Used in Making Computations. From the Association of Commerce Committee, a list was obtained of the number of steam locomotives used in the Chicago city limits in October, 1911. This list, showing the number of locomotives and locomotive hours in each class of service, was as follows:

Service	Number of locomotives	Working hours per day
Through freight	361	812
Switching	560	7223
Transfer	182	2378
Through passenger	336	801
Suburban passenger	200	1000

An estimate was made of the coal consumption per working hour of each class of freight locomotive, and from the coal burned in the city limits per day the necessary electrical requirements for the same service were computed.

OCTOBER, 1911—CITY LIMITS

	Through freight	Switching	Transfer	Total
Number of locomotives	361	560	182	1,103
" " working hours per day	812	7,223	2,378	10,413
*Lb. of coal per locomotive per hour	2,000	600	1,350	—
Tons of coal per day	812	2,196	1,602	4,610
Lb. of coal per hour	67,670	183,083	133,500	384,253
*Lb. of coal per hour per locomotive draw-bar horse-power	10	12	10	
*Efficiency (from draw-bar to power house)	60%	60%	60%	
Average electrical load in kw	8,675	19,072	16,473	44,220
*Watt-hours per ton-mile	31	120	56	
Ton-miles per day	6,767,000	3,821,814	7,036,610	17,625,424

*Assumptions.

The pounds of coal per locomotive per working hour were assumed as shown above after consulting with several Chicago railway men. The tons of coal per day obtained in this way check very closely with similar figures published in the 1911 report of the Chicago Smoke Department, which figures were obtained directly from the railroad companies.

The pounds of coal per hour per draw-bar horse power was assumed after discussing the subject with a prominent engineer of one of the large trunk line railroads. As a result of many actual tests he found that his road used about eight lb. of eastern coal per draw-bar horse power. Correcting this figure for the difference in the heat value of the coal, the above figures were obtained for Chicago.

The efficiency of 60 per cent between the locomotive draw-bar and the electrical power house was also chosen after discussing the matter with the same engineer. This takes into account the losses in the line, the transformers, and in the motors and gears of the electric locomotive.

The " watt-hour per ton-mile " figures are in accordance with results obtained on several electrified roads.

Having thus obtained the average power house load in kilowatts for the city limits and the month of October, 1911, the following steps were taken:

1. The average load of 44,220 kw. was apportioned among the various railroads operating in the city.

2. The results were increased, so as to apply to the Association of Commerce electric zone instead of the city limits.

3. A study was made of the movement of freight cars during the different hours of the day, and the different months of the year. The increased traction on account of cold weather was also considered. The daily, monthly and yearly load factors were thus obtained.

4. The maximum demand and consumption was then computed for each railroad and each month of the year.

5. The results were checked in various ways.

Apportionment of Total Average Load Among the Railroads. The total average load was found to be 44,220 kw. for October and within the city limits. This was divided among the different railroads in accordance with the coal consumed by their freight engines as given in the Smoke Department report of 1911.

Increase of Figures to Cover Assn. of Commerce Electric Zone. A statement of the track mileage of all railroads for the city limits and for the zone, was obtained from the Association of Commerce committee. With this as a basis, and from a careful study of the map, the figures of average electrical load were increased to cover everything within the zone. The average increase in load was 22 per cent.

The following table gives the average load in kw. for October, for the area within the city limits and also for the area within the electric zone.

Load Factors, etc. A daily load factor of 75 per cent was assumed for the entire freight business of the Chicago district. Mr. L. C. Fritch (now chief engineer of the Chicago & Great Western R.R.) investigated the subject of electrification of the Chicago terminal of the Illinois Central R. R. in 1909. He, of course, had access to all the records of the railroad and his load curves for the freight service show a load factor of 75 per cent. The subject of the movement of freight cars through Chicago was also discussed with several railway officials connected with roads which are among the largest handlers of freight in the city, and from the information thus obtained, it seems certain that this figure is about right.

Average load in kilowatts, October, 1911, 54,000.

Maximum kilowatts, October, 1911, 75 per cent load factor, 72,100.

FREIGHT SERVICE
AVERAGE LOAD IN KILOWATTS. OCTOBER, 1911

Railroad	City limits	Per cent increase	Electric zone	Maximum kilowatts 75 per cent load factor
Wabash R.R.	980	20	1180	1570
C. I. & L. R.R.	460	15	530	710
L. S. & M. S. Ry.	1890	25	2370	3150
N. Y. C. & St. L. R.R.	620	20	760	1010
P. Ft. W. & C. Ry.	1950	25	2430	3250
B. & O. R.R.	830	50	1240	1660
M. C. R.R.	1740	20	2080	2790
Erie R.R.	1020	20	1220	1630
P. C. C. & St. L. R.R.	1320	15	1520	2030
C. Great Western Ry.	750	10	820	1090
Northwestern Ry.	4430	25	5550	7400
Rock Island Ry.	1530	20	1840	2450
C. B. & Q. R.R.	2970	25	3720	4950
St. Paul R.R.	2500	20	3000	4010
Ills. Central R.R.	2900	10	3180	4250
Santa Fe Ry.	580	15	670	890
C. & A. Ry.	1000	15	1150	1530
C. & E. I. R.R.	1940	20	2330	3100
Grand Trunk	700	25	870	1160
Wisc. Central	450	100	900	1200
C. & O. of Indiana	80	15	90	100
Chicago & Ind. Southern	100	15	110	140
Pere Marquette	230	15	260	350
Chi. & Western Ind.	640	10	700	930
B. & O.—C. T. R.R.	900	100	1800	2350
C. Junction	3400	0	3400	4550
E. J. & E. Ry.	1400	100	2800	3730
Belt Ry.	4900	5	5140	6870
Ch. W. Pullman & Southern	500	10	550	700
Ills. Northern	300	10	330	420
Mfg. Junction	100	25	120	160
Misc. Belt Roads	1100	25	1380	1940
Total	44,220		54,000	72,100

In order to get at the variation in the freight business throughout the year, the freight earnings of several of the principal railroads were plotted as shown in Fig. 21. The ratios obtained in this manner were used in getting the maximum kilowatts for each month of the year.

It was then decided to add to the maximum kilowatts of the winter months, the following percentages to take care of increased traction due to cold.

Month	Per cent added on account of cold
November	10
December	20
January	20
February	20
March	15
April	5

In getting at the monthly kw-hr., the Sunday requirements were assumed to be one-half of week-day requirements and four Sundays were used per month.

The following table shows the maximum kw., the kw-hr., and load factors for each month in the year.

FREIGHT ELECTRICAL REQUIREMENTS—CHICAGO

	Per cent of average daily earnings for October	Maximum kilowatts				Kw-hr.	Load factors
		Normal requirements	Additional on account of cold		Total maximum		
			Per cent	Amount			per cent
July, 1911	76.5	55,200	—	—	55,200	28,814,400	70.3
August	88.5	63,800	—	—	63,800	33,303,600	69.6
September	95.3	68,700	—	—	68,700	34,624,800	70.3
October	100	72,100	—	—	72,100	37,636,200	70.2
November	98.4	70,900	10	7,100	78,000	39,312,000	70
December	85.7	61,800	20	12,400	74,200	38,732,400	70.3
January, 1912	78.9	56,800	20	11,400	68,200	35,600,400	70.3
February	81.1	58,500	20	11,700	70,200	32,853,600	69.7
March	84.4	60,900	15	9,100	70,000	36,540,000	70.3
April	81.3	58,600	5	3,900	62,500	31,500,000	70.1
May	83.8	60,400	—	—	60,400	31,528,800	70.2
June	83.6	60,300	—	—	60,300	30,391,000	70
						410,837,200	

Average monthly load factor..... 70.1
Annual load factor............. 60.1

Normal maximum kilowatts assumed proportional to earnings.
Load factor for week day assumed at 75 per cent.
Sunday requirements ½ of week day, assuming four Sundays to month.

Ratio of Passenger to Freight Load:

Total kw.hr. per year, passenger	183,452,500	—	31 per cent
" " " " freight	410,837,200	—	69 per cent
" " " " passenger and freight	594,289,700	—	100 per cent

The 1911 report of the Chicago Smoke Department gives the average daily coal used by railway locomotives in city limits as follows:

Tons of coal per day, passenger	1163	—	21 per cent
" " " " " freight	4438	—	79 " "
" " " " " passenger and freight	5601	—	100 " "

This is a good check on the computations of the electrical energy required as to the proportion between passenger and freight service, for it is to be expected that locomotives engaged in freight service operate less efficiently than passenger locomotives.

Saving of Coal due to Electric Traction. The total electrical energy per year required by the electrified steam railroads of Chicago is:

Passenger service	183,452,500 kw-hr.
Freight	410,837,200 kw-hr.
Total	594,289,700 kw-hr.

At three lb. of coal per kw-hr. the total coal per year in the power houses would be 891,000 tons.

The 1911 report of the Chicago Smoke Department shows that the railroads burn in their steam locomotives about 1,850,000 tons of coal per year in the city limits. Increasing this figure by 22 per cent, it is seen that the railroads burn about 2,260,000 tons of coal per year in the electric zone. The ratio of the coal burned with electric operation to the coal burned with steam locomotives is 1 to 2.55.

Mr. W. S. Murray, electrical engineer of the New York, New Haven & Hartford R. R., in a paper presented at the 1911 convention of the A. I. E. E., said: " It has been demonstrated that the ratio between the coal burned for operating passenger trains by electric rather than by steam locomotives is 1 to 2. In the case of switching engines, this rate is much greater, a figure of 1 to 3 being conservative."

Tonnage of Freight handled in Chicago. It is surprising to find how little information there is available on this subject. The railroads do not keep their records so that the tons or car loads of freight handled in the Chicago district may be obtained. Apparently the only record of any sort that was ever kept of the freight movements was in 1902 and 1903 when a committee of Chicago railway officials made a report on the interchange of freight between the different roads. This report was made with particular reference to the clearing yards of the Chicago Union Transfer Company. A copy of this report was borrowed from Mr. L. C. Fritch and by means of it an estimate was made of the tonnage handled by the 18 principal railroads operating in Chicago. The figures given in this report cover the number of loaded and empty cars handled during the year ending June 30, 1903. To get at the tons of freight handled in the year ending June 30, 1912, the following assumptions were made:

Weight of empty freight car	18 tons
" " loaded " "	40 "
Days per year	330 "
Increase of freight business from 1903 to 1912	67 per cent

The last figure was obtained by plotting a curve of the total ton mileage of freight handled per year in the United States from 1902 to 1910. This information was obtained from Mr. Slasson Thompson's bureau of railway statistics. From the data given in the 1903 report it was also possible to approximate the number of switching movements, transfer movements and " in or out " or through freight movements.

After getting the number of tons of freight (including weights of cars) per day in each of these three classes of freight movement, by assuming the average distance travelled in each class of movement, the ton-miles were obtained. The mileages assumed were:

Through freight	7 miles
Switching	2 "
Transfer	10 "

It may seem surprising that the average transfer haul is longer than the average in or out haul, but this is undoubtedly true. The list previously given shows 2378 transfer locomotive hours per day as against 812 through freight locomotive hours.

Knowing the average ton-miles per hour and applying figures for " watt-hours per ton-mile," the average electrical load was obtained. The table on the following page shows the results of these computations.

As this 1903 Interchange report only covered the 18 principal trunk line railroads, the figures thus obtained serve only to check a part of the results arrived at by the other methods.

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Report—" Assembling—Interchange, Chicago, Illinois," by Committee of Railway Officials, 1903.

FREIGHT ELECTRICAL REQUIREMENTS—18 TRUNK LINE RAILROADS

	Through freight Ave. length of movement—7 miles Watt-hours per ton-mile—30			Switching Ave. length of movement—2 miles Watt-hours per ton-mile—120			Transfer Ave. length of movement—10 miles Watt-hours per ton-mile—60			Total ton miles per day	Total average kw.
	Tons per day	Ton-miles per day	Kw. average	Tons per day	Ton-miles per day	Kw. average	Tons per day	Ton-miles per day	Kw. average		
Wabash R. R.	32,018	224,126	280	33,735	67,470	337	14,392	143,920	360	435,516	980
C. I. & L. R.R.	15,647	109,529	137	16,066	32,132	161	6,720	67,200	168	208,861	460
L. S. & M. S. Ry.	60,232	421,624	527	68,141	136,282	681	27,323	273,230	683	831,136	1890
N.Y.C. & St.L. R.R.	21,876	153,132	191	25,256	50,512	253	7,328	73,280	183	276,924	620
P. Ft. W. & C. Ry.	62,312	436,184	545	71,868	143,736	719	27,574	275,740	689	855,660	1950
P. C. C. & St. L. R.R.	43,474	304,318	380	47,602	95,204	476	18,779	187,790	469	587,312	1320
B. & O. R. R.	23,990	167,930	210	27,425	54,850	274	13,915	139,150	348	361,930	830
M. C. R. R.	62,144	435,008	544	66,402	132,804	664	21,507	215,070	538	782,882	1740
Erie R. R.	30,369	212,583	266	36,819	73,638	368	15,393	153,930	385	440,151	1020
C. Gt. Western Ry.	23,769	166,383	208	24,910	49,820	249	11,540	115,400	288	331,603	750
Northwestern Ry.	122,091	854,637	1068	187,258	374,516	1873	59,602	596,020	1490	1,825,173	4430
Rock Island Ry.	50,007	350,049	437	64,853	129,706	648	17,797	177,970	445	657,725	1530
C. B. & Q. R. R.	83,010	581,070	726	136,838	273,676	1368	35,054	350,540	876	1,205,286	2970
St. Paul R. R.	90,580	634,060	792	108,788	217,576	1088	24,992	249,920	625	1,101,556	2500
Ill. Central R. R.	90,814	635,698	794	109,328	218,656	1093	40,459	404,590	1011	1,258,944	2900
Santa Fe Ry.	19,168	134,176	168	24,176	48,352	242	6,717	67,170	168	249,698	580
C. & A. Ry.	29,648	207,522	259	33,463	66,926	335	16,061	160,610	401	435,058	1000
C. & E. I. R. R.	61,460	430,220	538	62,779	125,558	628	30,898	308,980	772	864,758	1940
Total	922,607	6,458,249	8073	1,145,707	2,291,414	11,457	396,051	3,960,510	9896	12,710,173	29,420

Determination of Electric Power Required to Operate Passenger Trains at Chicago Terminals

General Plan. Observations were made on a mid-week day between 4 and 5 p.m. as to the number and kind of cars making up each train entering and leaving each of the six passenger stations now in operation.

At the Northwestern station and the Grand Central station these observations were extended to include all trains entering and leaving the station throughout a 24-hour period, these two being chosen as the ones representing the heaviest and lightest traffic, respectively.

From the data secured by observations, average weights of trains for the different classes of service were derived and from these weights and the special time schedules gotten out by the railroads for the use of their employees, the running time and average kilowatt demand for each train were calculated for all through trains for the entire 24 hours. Twenty-four-hour load curves were plotted from average weights of trains for the suburban service of the Northwestern and LaSalle stations, these stations being taken as typical of the suburban service of other stations.

Through trains were considered as being operated by locomotives and suburban trains as being made up of multiple-unit cars similar to those used by the New York Central, with two trailers to three motor cars. From these train diagrams, load curves were derived for the rush hours from 4 to 8 for the six terminal stations, the curve for through trains being determined separately from that of the suburban trains.

From the observations taken in the other stations between 4 and 8 p.m. suburban load curves were plotted for those hours and a total curve for suburban trains made up for the hours of 4 to 8 p.m., thus fixing the maximum for the suburban service at all stations.

Having determined the ratio of the combined suburban curve of the Northwestern and LaSalle stations to the total suburban curve for the hours of 4 to 8 p.m., this ratio was applied to the Northwestern and LaSalle stations' suburban curve for the remainder of the 24 hours in order to get the total suburban load curve.

Twenty per cent was added to the through train load to allow for increased traction due to cold weather and 50 per cent to suburban train load for increased traction and electric light and

heating. From these increased values the load curve for the winter months was made up.

The schedule of percentages of increase added during the fall and spring months for increased traction and heating which was used in connection with the freight power data, was applied to the passenger load curve for the purpose of determining the kilowatt-hour consumption for the different months of the year and the annual kilowatt-hour consumption.

Train Weights. The weights of trains were calculated on the following basis:

Locomotives	110	tons
Baggage, express and combination cars	60	"
Day coaches	40	"
Ordinary pullmans	62½	"
Steel pullmans	75	"
Diners	56	"
Trailer cars (suburban)	40	"

Method of Calculation. From the total weight of the train and the distance travelled in the zone the ton-miles were derived. For locomotive trains an energy consumption of 40 watt-hours per ton-mile was assumed; for the express run of suburban trains, 55 watt-hours per ton mile, and for the local run of express and local trains where stops are frequent—120 watt-hours per ton-mile. From the kilowatt-hours used by the train and the elapsed time as figured from the time schedules, the average kilowatts required by the train during the time of its run was calculated.

From the kilowatt demand of the trains the load curve was made up by the use of a train diagram showing the number of trains and the power taken by them at each half-hour interval except during the peak hours when the calculations were made for each 15 minutes.

Fig. 23 shows how the through passenger load would vary throughout the year, making proper allowances for increased traction due to cold weather, also taking into account the variation in the amount of business done. It is assumed that the amount of energy required for the different months, exclusive of traction due to cold, would differ from January by a percentage equal to one-half the per cent difference between the earnings for January and the other months of the year.

Fig. 24 shows the suburban requirements of the year; the normal requirements are assumed as constant and the additional due to increased traction and heat are shown.

TOTAL LOAD CHICAGO THROUGH TRAINS

Time	Grand Central	North-western	LaSalle	Union	Dearborn	I.C.	Total kw.
A.M. 12:00	—	—	1600	1470	2090	1340	6,500
12:30	360	—	610	1470	340	1180	3,960
1:00	360	—	610	—	—	—	970
1:30	—	—	250	730	—	—	980
2:00	—	—	1180	—	—	—	1,180
2:30	—	—	1190	—	720	—	1,910
3:00	—	620	1400	1900	590	1490	6,000
3:30	—	—	—	580	—	1360	1,940
4:00	—	—	—	—	—	—	—
4:30	—	140	—	—	—	—	140
5:00	—	140	160	—	—	—	300
5:30	—	—	—	—	—	550	550
6:00	560	—	1750	990	—	550	3,850
6:30	560	1180	3940	4220	2860	1570	14,330
7:00	280	1760	3540	4380	2640	2710	15,310
7:30	530	2400	4650	3880	2710	2370	16,540
8:00	1270	1990	3280	3990	940	940	12,410
8:30	1130	3350	4450	2390	810	940	13,070
9:00	1140	3060	3100	3000	3100	390	13,790
9:30	—	2750	2620	3330	3300	1680	13,680
10:00	370	2810	1830	4220	750	3280	13,260
10:30	370	1320	3830	2410	1090	2590	11,610
11:00	—	3750	3170	1600	1270	1050	10,840
11:30	—	1050	1600	2200	1810	540	7,200
P.M. 12:00	310	1050	2280	2060	1950	580	8,230
12:30	580	720	1510	—	2710	570	6,090
1:00	960	560	1930	700	650	1280	6,080
1:30	—	2080	1940	1730	540	1200	7,490
2:00	—	200	1160	1900	540	—	3,800
2:30	—	850	2420	—	—	—	3,270
3:00	470	1250	1580	1670	1700	1120	7,790
3:30	—	1650	3000	1380	980	560	7,570
4:00	890	930	1240	1880	590	450	5,980
4:30	890	1890	2630	2520	1550	2070	11,550
5:00	730	750	3280	2230	1580	930	9,500
5:30	270	1040	4190	3530	1160	930	11,120
6:00	440	750	2530	2730	1300	1530	9,280
6:30	930	3080	630	2490	—	1530	8,660
7:00	320	2240	1340	—	920	1780	6,600
7:30	—	460	1300	1560	590	1860	5,770
8:00	—	1010	1660	2350	720	1820	7,560
8:30	—	3000	2510	3160	1370	1810	11,850
9:00	—	1480	3010	1480	2900	1710	10,580
9:30	840	—	1860	590	2080	1630	7,000
10:00	870	610	940	2950	1140	1660	8,170
10:30	870	1800	1990	3410	870	580	9,520
11:00	—	1200	980	590	510	—	3,280
11:30	430	—	2310	—	1710	—	4,450
12:00	—	—	1600	1470	2090	1340	6,500

The above figures do not include the allowance for increased traction during winter months.

Summary, Electrical Requirements for Passenger Service

Normal Requirements. The suburban service is assumed the same as January throughout the year. Sundays, for the suburban service, are assumed 33⅓ per cent of a week-day.

REQUIREMENTS OVER NORMAL

	Suburban and through increased traction on account of cold	Surburban only heat
November	10 per cent	15 per cent
December	20 " "	30 " "
January	20 " "	30 " "
February	20 " "	30 " "
March	15 " "	20 " "
April	5 " "	10 " "

	Daily earnings over January expressed in per cent	Coincident maximum kilowatts			
		Through	Suburban	Light and power for depots, offices shops, etc.	Grand total
July, 1911	12.6	11,490	37,310	3550	52,350
August	18.8	12,120	37,310	3550	52,980
September	17.6	12,000	37,310	4000	53,310
October	10.4	11,260	37,310	4250	52,820
November	5.9	11,880	46,640	4570	63,090
December	5.7	12,940	55,960	4850	73,750
January, 1912	—	12,240	55,960	4850	73,750
February	0.2	12,260	55,960	4570	72,790
March	0.3	11,760	50,370	4250	66,380
April	1.7	10,890	42,910	4000	57,800
May	2.6	10,470	37,310	3550	51,330
June	10.3	11,250	37,310	3550	52,110

	Kilowatt-hours				Load factor
	Through	Suburban	Light and power per month	Grand	
July, 1911	6,633,600	5,679,200	1,850,200	14,163,000	36.4%
August	7,045,700	5,816,700	1,882,700	14,745,100	37.4%
September	6,743,500	5,611,400	1,836,500	14,191,400	36.9%
October	6,504,000	5,679,200	1,895,000	14,078,200	35.8%
November	6,680,000	7,014,300	1,895,000	15,589,300	34.3%
December	7,472,500	8,518,800	2,068,000	18,059,300	32.8%
January, 1912	7,116,800	8,725,100	2,104,200	17,946,100	32.9%
February	6,658,700	8,109,200	1,816,600	16,584,500	32.7%
March	6,795,500	7,666,900	1,895,000	16,357,400	33.1%
April	6,123,400	6,453,100	1,836,500	14,413,000	34.6%
May	6,085,000	5,816,700	1,882,700	13,784,400	36 %
June	6,281,700	5,473,800	1,785,300	13,540,800	36.1%
Total	80,140,400	80,564,400	22,747,700	183,452,500	28.3%

Through-train requirements for different months were obtained by increasing the January figures by one-half the excess of the daily passenger earnings of those months. Sunday, for through-trains, is taken as 80 per cent of a week-day.

The energy required for light and power for depots, offices, shops, etc., battery charging and operating switches is assumed at 5000 kw. maximum and 50 per cent annual load factor.

Calculation of Transmission and Conversion System for Passenger and Freight Loads

To determine the location and size of substations required for the supply of the third rail system, the positions of all passenger trains which will be operating in the electric zone at 6:05 p.m., the time of the evening peak, were indicated upon a railroad map of Chicago, these positions being determined from the train schedules. No train schedules were available for freight trains and it was therefore necessary to locate these on the map in amounts approximately equal to the demand of a single train, chiefly near the freight yards where switching is the heaviest, a few trains being located along the main line.

Two general plans of power supply were assumed (a) based on the installation of a separate power system for each road or group of roads using the same tracks or operating under allied financial interests, and (b) based upon the entire power supply being operated as a unified system, the energy being derived from the nearest station of the Commonwealth Edison Co. or the Public Service Co. and all stations being used to supply all the roads which came within an economical radius thereof.

The position of substations was then fixed by allowing a distance of four to five miles apart on the larger roads and six miles apart on the smaller ones.

In scheme (a) where operation is contemplated by groups, power houses were located at points where condensing water was available, where it was possible to secure such sites within a reasonable distance of the railroad company's tracks.

However, in the smaller system where the loads were from 5000 to 10,000 kw. this was not entirely feasible and sites were selected in some cases with reference to the distribution of the load.

In selecting the capacity for generating stations under group operation, it was considered that from 50 per cent to 75 per cent surplus capacity would be required to take care of swings in the load and provide suitable reserve.

Fig. 26 shows swings of nearly 100 per cent over one hour maximum for New York, New Haven & Hartford Cos Cob station.

Transmission lines were laid out on a basis of a line for each 3000 kw. of load with a reserve line for each substation. The reserve supply was secured in the smaller substations by using one line with taps to two or three substations.

In the plan for unified power supply it was assumed that the present 600-volt substations of the surface and elevated roads would be available, when increased in capacity, as sources of 600-volt supply for all roads coming within an economical range of their distribution, and the necessary number of additional lines to these substations to supply the steam railroad load are included in the estimates.

It is assumed that transmission lines would be run overhead along the railroad company's right-of-way in the outlying portions of the city where steel pole construction of a substantial character could be employed. Wherever lines were run on public streets it was assumed that they would be carried underground.

Summary of Results

Under a unified plan of power supply, only 21 additional substations would have to be established and the total number would be only 43 as compared with 72 substations under group operation.

The number of transmission lines under the unified plan would be 81 as compared with 132 under group operation, and there would be over $2\frac{1}{2}$ times the length of line required for group operation as compared with the unified plan.

The data for the unified plan are as follows:

Number of substations	43
Number of lines	81
Capacity of substations kw.	205,000
Capacity of generating stations, kw.	142,000
Length of lines, feet	1,390,000

The data for group operation appear in the following table.

A comparison of the investment necessary for unified power supply, as compared with a separate supply for each road or group of roads, shows the following saving in favor of unified power supply:

Power-house capacity	99,500 kw.
Substation capacity	39,500 kw.
Transmission line cables in feet	2,283,000 kw.

Railroads	Kilowatts			Capacity in kilowatts				
	Freight load	Pass. load	Total load	Generating stations	Substations	No. of substations	No. of lines	Length of lines
1. Ill. Cent.								
M. C. Pass.	4,600	20,400	25,000	37,500	37,000	7	19	329,000 ft.
2. L. S. & M. S.								
M. C. R. R. Freight.								
C. R. I. & P. Pass.	8,750	7,750	16,500	24,000	28,000	7	14	255,000 ft.
3. C. & N. W.	8,000	25,000	33,000	50,000	51,000	8	19	479,000 ft.
4. C. M. & St. P.	4,350	3,050	7,400	14,000	14,000	4	8	121,000 ft.
5 C. & Gt. W.								
Grand Trunk.								
B. & O. C. T.								
I. H. Belt.	10,500	2,000	12,500	22,500	26,500	15	21	1,224,000 ft.
6. P. F. & W. & C.								
P. C. C. & St. L.	5,700	2,000	7,700	14,000	20,000	10	12	637,000 ft.
7. Erie.								
C. I. & L.								
C. & W. I.								
Wabash.								
Belt.	16,300	3,200	19,500	30,000	32,000	10	18	290,000 ft.
8 Santa Fe.								
Alton.	2,600	2,000	4,600	9,000	6,000	2	4	29,000 ft.
9. C. B. & Q.	5,400	5,400	10,800	16,500	14,000	3	8	47,000 ft.
10. C. R. I. & P.	2,400	3,000	5,400	9,000	9,000	3	6	15,000 ft.
11. Chicago Junction.	5,000	—	5,000	9,000	—	—	—	—
12. E. J. & E.	4,100	—	4,100	6,000	7,000	3	3	237,000 ft.
Total.	77,700	73,800	151,500	241,500	244,500	72	132	3,673,000 ft.

In addition to the above saving, there is a corresponding saving in conduit construction, where the lines are underground, and in pole line construction, where the lines are overhead.

There is also a corresponding and possibly even greater saving in the 600-volt feeder, cable and conduit or pole lines for same.

It must also be borne in mind that, where the stations and substations are of larger average capacity, the investment per kilowatt is less than where the same load is distributed over a larger number of stations and substations. This same principle applies to transmission and distribution cable and conduit, and pole lines.

Also the same principle applies, to fully as great an extent, to the operating and maintenance cost of stations, substations and lines.

SUMMARY

TOTAL ELECTRICAL REQUIREMENTS—ALL STEAM ROADS

	Load at time of monthly maximum demand		
	Freight	Passenger	Total
July, 1911	54,250	52,350	106,600
August	62,700	52,980	115,680
September	67,500	53,310	120,810
October	70,900	52,820	123,720
November	76,700	63,090	139,790
December	73,000	73,750	146,750
January, 1912	67,000	73,020	140,020
February	69,000	72,790	141,790
March	68,800	66,380	135,180
April	61,400	57,800	119,200
May	59,400	51,330	110,730
June	59,300	52,110	111,410

	Kilowatt-hours			
	Freight	Passenger	Total	Load factor
July, 1911	28,814,400	14,163,000	42,977,400	54.3%
August	33,303,600	14,745,100	48,048,700	55.8%
September	34,624,800	14,191,400	48,816,200	56.2%
October	37,636,200	14,078,200	51,714,400	56.4%
November	39,312,000	15,589,300	54,901,300	54.7%
December	38,732,400	18,059,300	56,791,700	52 %
January, 1912	35,600,400	17,946,100	53,546,500	51.5%
February	32,853,600	16,584,500	49,438,100	51.8%
March	36,540,000	16,357,400	52,897,400	52.5%
April	31,500,000	14,413,000	45,913,000	53.4%
May	31,528,800	13,784,400	45,313,200	55 %
June	30,391,000	13,540,800	43,931,800	55 %
Total	410,837,200	183,452,500	594,289,700	46.2 %

A paper presented at the 29th Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June 28, 1912.

SINGLE-PHASE INDUCTION MOTORS

BY W. J. BRANSON

The purpose of this paper is to develop a complete vector analysis of single-phase induction motor performance as the basis for an accurate circle diagram applicable to motors of even the smallest commercial sizes. To accomplish this, it will be necessary to derive mathematically correct formulas or graphical construction for several quantities and relations which have been treated very loosely heretofore. Of these the most important are

1. The value of the secondary no-load current, as reflected in the primary.
2. The construction of the current circle.
3. The revolutions per minute.

The analysis by which the required formulas and graphical processes are to be derived will be based on the transformer theory of the induction motor as distinguished from the rotating field theory. At the outset, therefore, it is necessary to consider some of the general problems involved in the phenomena of primary-secondary transformation as affected by magnetic leakage.

I. Primary-Secondary Transformation

Fig. 1 represents a transformer having magnetizing and leakage characteristics similar to those of an induction motor. For the purpose of simplification, it will be assumed for the present that the primary and secondary windings have 1 to 1 ratio and that the resistances of both primary and secondary, as well as the iron loss, are negligible.

Let

K_p = $\dfrac{\text{permeance of mutual path.}}{\text{permeance of mutual and primary leakage paths in parallel.}}$

K_s = $\dfrac{\text{permeance of mutual path.}}{\text{permeance of mutual and secondary leakage paths in parallel.}}$

L_1 = coefficient of self-induction of primary.

L_2 = coefficient of self-induction of secondary.

M = coefficient of mutual induction.

P = $2\,\pi$ frequency.

i_m = The primary magnetizing current, *i.e.*, the current which flows in the primary with the secondary open.

From the physical meaning of K_p and K_s as given above,

$$K_p\, L_1 = M$$

$$K_s\, L_2 = M$$

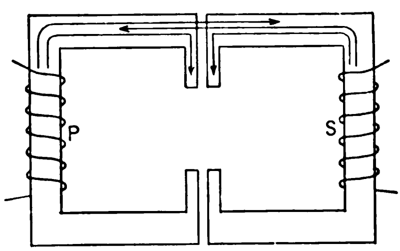


FIG. 1

Since, by definition, the reactance of a simple inductive circuit is equal to $P\,L$, it is evident that the reactance of the primary winding when the secondary circuit is open,

$$X_0 = P\,L_1$$

Therefore, the magnetizing current

$$i_m = \frac{E}{P\,L_1}$$

and the e.m.f. induced in the primary winding is represented by the expression

$$P\,L_1\,i_m$$

At the same time an e.m.f. is induced in the secondary equal to

$$P\,L_1\,i_m\,K_p$$

or

$$P\,M\,i_m$$

In other words, the current i_m produces a flux which induces in the primary winding an e.m.f. equal to $P\,L_1\,i_m$ and the portion of this flux which enters the secondary core induces in the secondary winding an e.m.f. equal to $P\,M\,i_m$. When the secondary circuit is open, these are the actual e.m.fs. in the primary and secondary windings. When the secondary circuit is closed, however, the m.m.f. of the secondary current opposes and partially neutralizes the m.m.f. of the primary current.

Under load conditions, therefore, the expressions given above do not represent actually existing e.m.fs. The actual e.m.f. values are obtained by taking the vector sum of the e.m.f. which the flux due to the primary current would induce if the secondary current did not exist, and the e.m.f. which the flux due to the secondary current would induce if the primary current did not exist.

The mathematical relation between the current values of these hypothetical e.m.f. values, which become actual values only when there is no reaction between the primary and secondary, are expressed by the equations which follow:

If i represents the primary current and e_1 the primary e.m.f. due to the flux produced by i,

$$e_1 = i\,\frac{P\,M}{K_p} \tag{1}$$

and

$$i = e_1\,\frac{K_p}{P\,M} \tag{2}$$

If e_2 represents the e.m.f. induced in the secondary by the flux produced by i,

$$e_2 = i\,P\,M \tag{3}$$

and

$$i = \frac{e_2}{P\,M} \tag{4}$$

If i_2 represents the secondary current and e_2 the secondary e.m.f. due to the flux produced by i_2,

$$e_2 = i_2\,\frac{P\,M}{K_s} \tag{5}$$

and

$$i_2 = e_2\,\frac{K_s}{P\,M} \tag{6}$$

If e_1 represents the e.m.f. induced in the primary by the flux produced by i_2,

$$e_1 = i_2 P M \tag{7}$$

and

$$i_2 = \frac{e_1}{P M} \tag{8}$$

In applying this method of analysis to the problems which immediately follow, and which lead to the derivation of an expression for reactance, the resistance of both windings and the iron loss will be treated as negligible.* The hypothetical e.m.fs. will therefore be either in phase or directly opposed and may be added or subtracted directly.

1. *Relative value of primary and secondary currents when the secondary is short-circuited.*

Let i_h = primary current.
i_{2h} = secondary current.

Secondary e.m.f. due to $i_h = P M i_h$ (equation 3)

Secondary e.m.f. due to $i_{2h} = \dfrac{P M i_{2h}}{K_s}$ (equation 5)

There is no resistance drop and there can be no induced e.m.fs. other than those represented by the above expressions, since all fluxes have been taken account of. Therefore the e.m.fs. corresponding to the primary and secondary currents respectively are equal and directly opposed.

$$P M i_h = \frac{P M i_{2h}}{K_s}$$

$$i_{2h} = i_h K_s$$

This shows that, when the resistances and iron loss are negligible, the secondary short-circuit current is equal to the current existing at the same time in the primary multiplied by K_s.

2. *Demagnetizing Effect of Secondary Current.*

Primary e.m.f. due to $i_{2h} = P M i_{2h}$ (equation 7)

The above e.m.f. opposes and neutralizes an equal component of the e.m.f. due to the primary current which balances the

*Primary resistance will be neglected in all discussions preceding Section VII, and iron loss will be neglected in all discussions preceding Section VIII. Both quantities will be correctly treated in the working diagram.

impressed e.m.f. This leaves a portion of the impressed e.m.f. unbalanced and, as a consequence, a larger primary current flows. The primary current must increase until the balance is restored between impressed and induced e.m.fs., that is, until the e.m.f. due to the added primary current equals and neutralizes the e.m.f. due to i_{2h}.

The additional primary current required will be

$$P\ M\ i_{2h} \times \frac{K_p}{P\ M} \qquad \text{(equation } \mathbf{2}\text{)}$$

or

$$i_{2h}\ K_p$$

This shows that the increase in the value of the primary current due to the demagnetizing effect of the secondary current equals

$$\text{secondary current} \times K_p$$

3. *Relative value of the primary current with the secondary open and the primary current with secondary short-circuited.*

From (1) above, $i_{2h} = i_h\ K_s$

From (2) the increase of primary current due to the demagnetizing effect of i_{2h} equals

$$i_{2h}\ K_p$$

or, substituting from (**1**),

$$i_h\ K_p\ K_s$$

This is the additional primary current due to short-circuiting the secondary.

Therefore, the total primary current

$$i_h = i_m + i_h\ K_p\ K_s$$

$$i_m = i_h - i_h\ K_p\ K_s$$

$$= i_h\ (1 - K_p\ K_s)$$

$$i_h = \frac{i_m}{1 - K_p\ K_s}$$

4. *Equivalent Reactances.* Let X_1 = equivalent reactance (total) reduced to primary, such that, neglecting the effect of resistance and iron loss, if E be impressed on the primary with secondary short circuited, the current equals E/X_1.

Let X_2 = equivalent reactance (total) reduced to secondary, such that if E be impressed on the secondary with primary short circuited, the current equals E/X_2.

By definition,

$$\frac{E}{X_1} = i_h$$

$$= \frac{i_m}{1 - K_p K_s}$$

$$X_1 = \frac{(1 - K_p K_s)\, E^*}{i_m}$$

$$= \frac{(1 - K_p K_s)\, P L_1\, i_m}{i_m}$$

$$= \frac{(1 - K_p K_s)\, P M}{K_p}$$

By similar reasoning it may be shown that

$$X_2 = \frac{(1 - K_p K_s)\, P M}{K_s}$$

II. Transformer Current Locus

Neglecting the effect of primary resistance, the current locus of a transformer is represented by a semicircle drawn on $M H$ (Fig. 2) as a diameter. The correctness of this construction is demonstrated as follows:

Draw the base line $O H$ equal to E/X_1 and locate M by making $O M$ equal to i_m. Also draw the lines $O L$ and $M L$ to represent the primary and secondary currents.† At right angles to $O L$ draw the line $O W$ to represent a primary e.m.f. equal to $P L_1 i$ and the line $O Y$ to represent a secondary e.m.f. equal to $P M i$. Also, lay off at right angles to $M L$ the line $E W$ equal to $P M i_2$ and the line $D Y$ equal to $P L_2 i_2$.

*The product of $K_p K_s$ which is represented by the symbol (K_r) may be derived from i_m and X_1 as follows:

$$X_1 = \frac{(1 - K_p K_s)\, E}{i_m}$$

$$\frac{i_m X_1}{E} = 1 - K_p K_s$$

$$1 - \frac{i_m X_1}{E} = K_p K_s$$

$$= K_r$$

†It should be noted that $M L$ represents, directly, the current which flows in the primary as a result of the demagnetizing effect of the secondary current. This equals secondary current multiplied by K_p. Therefore in terms of the primary current scale $M L = i_2 K_p$.

The vector sum $D\,O$ of the two secondary e.m.fs. $P\,M\,i$ and $P\,L_2\,i_2$ is the resultant e.m.f. in the secondary and is, consequently, equal to the secondary resistance drop.

Centering attention now on the triangle $O\,W\,E$, it will be noted that

$$\begin{aligned} E\,W &= P\,M i_2 \\ &= P\,L_1\,i_2\,K_p \\ &\propto P\,L_1 \times M\,L \end{aligned}$$

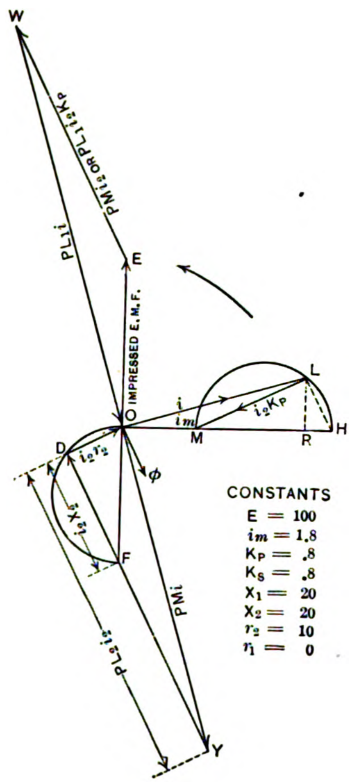


FIG. 2

and since

$$\begin{aligned} O\,W &= P\,L_1\,i \\ &\propto P\,L_1 \times O\,L \end{aligned}$$

it is evident that $E\,W$ is to $M\,L$ as $O\,W$ is to $O\,L$, and since the the angles at W and L are equal, it follows that the triangle $O\,W\,E$ is similar to the triangle $O\,L\,M$ and therefore $O\,E$ is at right angles to $O\,M$.

Continue the line $E\,O$ to intersect $D\ Y$ at F. Since $O\,F$ has been constructed at right angles to $O\,M$, $O\,Y$ at right angles to $O\,L$ and $F\,Y$ at right angles to $M\,L$, it is evident that the triangle $O\,Y\,F$ is also similar to $O\,L\,M$ and therefore similar to $O\,W\,E$, and since the side $E\,O$ of the triangle $O\,W\,E$ is of constant length, being proportional to the impressed voltage, the corresponding side $O\,F$ of the triangle $O\,Y\,F$ is also of constant length.

From the similarity of the triangles, it is evident that

$$F\,Y = O\,Y\frac{E\,W}{O\,W}$$

and the voltage represented by

$$\begin{aligned} F\,Y &= P\,Mi\,\frac{P\,Mi_2}{P\,L_1 i} \\ &= P\,Mi\,\frac{P\,Mi_2}{P\,Mi/K_p} \\ &= P\,Mi_2\,K_p \end{aligned}$$

It will be noted by reference to the figure that

$$F\,D = D\,Y - F\,Y$$

therefore the voltage represented by

$$\begin{aligned} F\,D &= \frac{P\,Mi_2}{K_s} - P\,Mi_2\,K_p \\ &= i_2\,\frac{(1-K_p\,K_s)\,P\,M}{K_s} \\ &= i_2\,X_2 \\ &= i_2 \text{ times equivalent reactance reduced to the secondary.} \end{aligned}$$

That is, the voltage represented by line $F\,D$ equals i_2 multiplied by X_2, the latter being a constant. Therefore $F\,D$ is proportional to i_2 and may represent it in value though not in phase.

As regards phase, $F\,D$ is, by construction, at right angles to i_2, and $D\,O$, which represents the secondary resistance drop, is in phase with i_2. Therefore $F\,D\,O$ is a right angle.

It has now been shown that the line OF is of constant length and that the angle at D is a right angle. Therefore, the locus of the line FD, which is proportional to the secondary current, is a semicircle. It follows that the locus of the secondary current vector is also a semicircle. In other words, if the secondary resistance be varied from zero to infinity, the point L will move from H to M along the semicircle MLH.

Inasmuch as the triangles FDO and MLH are similar, it is evident that in value, though not in phase, the line ML may represent i_2X_2, and the line LH may represent i_2r_2. It is necessary, in connection with formulas to be developed later, to note the scale to which the reactance and resistance drops are represented by these lines.

Let S_e = volts per inch.

S_1 = primary amperes per inch.

$S_2 = S_1/K_p$ = secondary amperes per inch.

Since $i_2 X_2$, the reactance drop, is represented by the same line (ML) as the secondary current (i_2), it follows that

$$\frac{i_2}{S_2} = \frac{i_2 X_2}{S_e}$$

$$S_e = S_2 X_2$$

$$= \frac{S_1 X_2}{K_p}$$

This shows that the e.m.f. scale equals the secondary current scale multiplied by X_2. In other words,

$$\text{Reactance drop} = M L \times S_2 X_2 \text{ volts}$$

and

$$\text{Resistance drop} = L H \times S_2 X_2 \text{ volts.}$$

It should also be noted that the secondary resistance drop is equal to the secondary current vector multiplied by

$$\frac{r_2}{X_2} S_e$$

This may be demonstrated as follows,

$$i_2 r_2 = L H \times S_e$$

$$= M L \frac{L H}{M L} S_e$$

$$= M L \frac{i_2 r_2}{i_2 X_2} S_e$$

$$= M L \frac{r_2}{X_2} S_e$$

Another relation which is important in practical work may be derived from the above. Since

$$L H \times S_e = M L \frac{r_2}{X_2} S_e$$

it follows that

$$\frac{L H}{M L} = \frac{r_2}{X_2}$$

In determining the starting torque of a single-phase induction motor, it is convenient to make use of the fact that the resultant flux in the secondary is proportional to

$$L H S_2 \sqrt{X_2}$$

It was shown above that the secondary resistance drop, which is equal to the e.m.f. induced in the secondary, is represented by the expression

$$L H S_2 X_2$$

For a given flux the e.m.f. induced in the secondary varies as the turns, or as the square root of the reactance.

$$L H S_2 X_2 \propto \phi \sqrt{X_2}$$

$$\phi \propto \frac{L H S_2 X_2}{\sqrt{X_2}}$$

$$\propto L H S_2 \sqrt{X_2}$$

as stated above.

III. Effects of Rotation in the Two-Phase Motor

Inasmuch as an induction motor, under locked conditions, is simply a transformer with a short-circuited secondary, the foregoing may be considered to be an analysis of the flux e.m.f. and current relations which exist when the rotor is at rest in either a single-phase induction motor or in one phase of a polyphase induction motor. The next step is to include in this analysis the effects of rotation.

The flux, e.m.f. and current relations in the rotor of a single-phase induction motor are very complicated and difficult to analyze directly. The most satisfactory method of procedure is to take the simpler relations of the two-phase motor as a basis

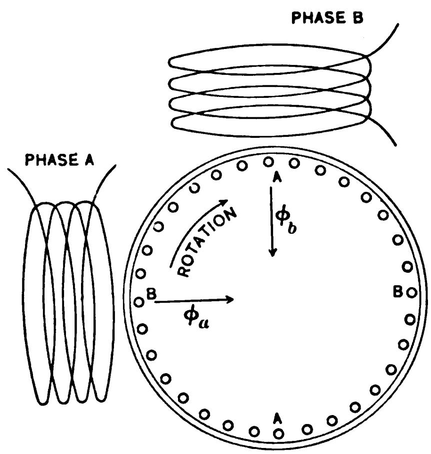


Fig. 3

or point of departure and consider the changes which must take place in the rotor when one primary phase is disconnected from the line. In order to make use of this method, we must make a preliminary analysis of the effects of rotation in the two-phase induction motor.

Fig. 3 represents the electric and magnetic circuits of a two-phase induction motor, equipped with a squirrel cage rotor. If an alternating e.m.f. be impressed on phase B, a flux ϕ_b will appear in the rotor core and the e.m.fs. induced in the rotor conductors will cause a current to circulate in the plane $B\,B$. Similarly, if an e.m.f. be impressed on phase A, the flux ϕ_a will appear and a current will circulate in the plane AA. If the rotor be allowed

to rotate, these currents will continue to circulate in the same planes, passing through whatever conductors and whatever parts of the end rings happen at the instant to be in the right position. In other words, the two secondary circuits remain fixed in the planes *A A* and *B B* whether the rotor is in motion or at rest. These two secondary circuits will be designated circuit *A* and circuit *B* respectively. It will be noted that circuit *A* is in inductive relation with phase *A*, while circuit *B* is in inductive relation with phase *B*.

It will be evident from Fig. 3 that when the rotor is in motion the conductors constituting circuit *A* will cut the flux ϕ_b and also that the conductors of circuit *B* will cut the flux ϕ_a. An e.m.f. due to rotation will therefore be generated in each circuit.

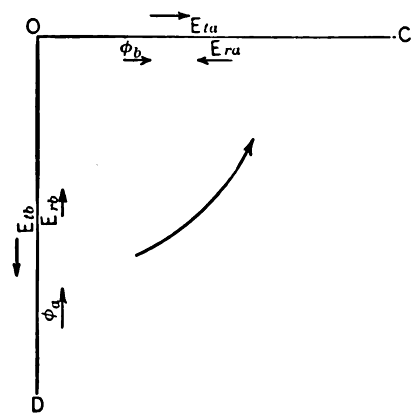


FIG. 4.—REPRESENTS CONDITIONS AT THE INSTANT WHEN IMPRESSED E.M.F. IS AT THE POSITIVE MAXIMUM, FOR PHASE *B*.

It may easily be demonstrated that in each circuit the rotational e.m.f. is directly opposed in phase to the transformer e.m.f. which caused the rotor current referred to above, and also that at synchronous speed the transformer and rotational e.m.fs. will be not only opposed in phase, but exactly equal, so that no currents will flow in the rotor.

Throughout the following pages these rotor e.m.fs. will be designated by the letter *E* with the subscript *t* or *r* indicating transformer or rotational and *a* or *b* indicating the circuit.

E_{tb} = transformer e.m.f. in circuit *B*
E_{rb} = rotational e.m.f. in circuit *B*.
E_{ra} = rotational e.m.f. in circuit *A*.
E_{ta} = transformer e.m.f. in circuit *A*.

Fig. 4 shows the phase relations of the fluxes and secondary e.m.fs. of a two-phase motor running at synchronous speed, *i.e.*, mechanically driven at synchronous speed by external power.

The flux e.m.f. and current relations in one phase of a two-phase induction motor, when the rotor is at rest, are represented in the transformer diagram Fig. 2. Assuming the resistance of both primary and secondary as well as the iron loss to equal zero, the primary current

$$i_h = \frac{E}{X_1}$$

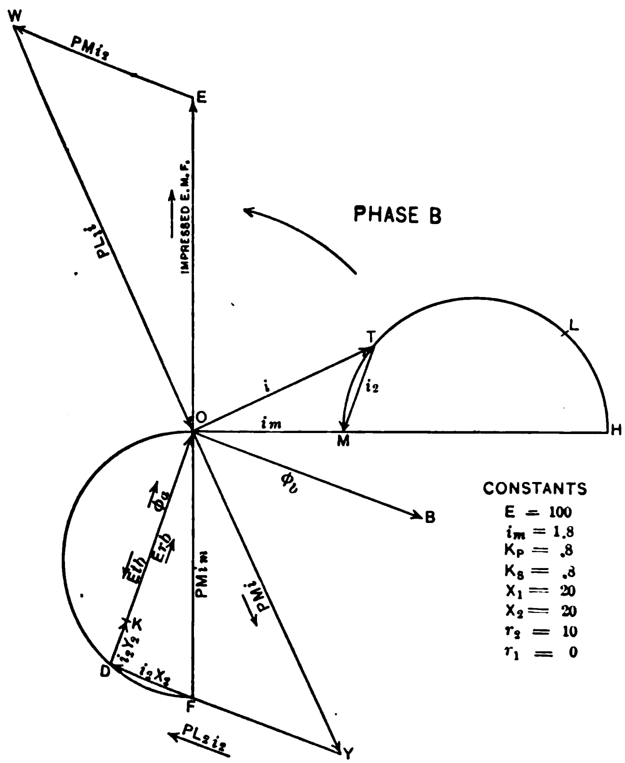


FIG. 5

and is represented by OH. In case, however, of an actual motor, having a *secondary* resistance greater than zero, the end of the locked current vector will be at some point on the semicircle, as at L. When the motor is running at synchronous speed, and no current flows in the rotor, the primary current will have the same value $i_m = E/X_0$ that would exist if the rotor were open-circuited.

From the last statement, it is evident that rotation at synchronous speed has the same effect on the primary current as a rotor resistance of infinite value. Similarly, as will now be shown, rotation at any speed below synchronism has the same effect on the current values as the introduction of a resistance of some finite value into the rotor circuit.

Referring to Fig. 5, which represents the flux e.m.f. and current values of phase B under operating conditions, it will be noted that the resultant rotor flux ϕ_b is at right angles to the secondary current. The resultant flux of phase A will therefore be in phase with the secondary current of phase B. Consequently the e.m.f. (E_{rb}) generated in circuit B by rotation through the flux of phase A will add directly to the resistance drop, and the effect of rotation on the current values is the same that would result from increasing the secondary resistance to such an extent as to make the resistance drop equal to

$$i_2\, r_2 + E_{rb}$$

Since any rotational e.m.f. equals a transformer e.m.f. due to the same flux mutiplied by

$$\frac{\text{rev. per min.*}}{\text{synchronous speed}}$$

it follows that

$$\frac{\text{rev. per min.}}{\text{syn.}} = \frac{E_{rb}}{E_{ta}}$$

and since in a two-phase motor E_{ta} is equal to E_{tb}, the fluxes being equal,

$$\frac{\text{rev. per min.}}{\text{syn}} = \frac{E_{rb}}{E_{tb}}$$

$$= \frac{O\,K}{O\,D}$$

$$= \frac{O\,D - D\,K}{O\,D}$$

$$= \frac{T\,H - M\,T\,\frac{r_2}{X}\dagger}{T\,H}$$

*For sinusoidal space distribution of flux.

†As will be shown later $O\,D = T\,H \times \dfrac{S_1\,X_2}{S_e\,K_p}$. Also, as shown below.

$D\,K\,S_e = i_2\,r_2 = M\,T\,\dfrac{S_1}{K_p}\,r_2$ and $D\,K = M\,T\,\dfrac{S_1\,r_2}{S_e\,K_p}$.

This expression equals secondary efficiency, as will be evident from the following:

$$\text{Secondary input} = E_{tb} \times i_2$$

$$\text{Secondary copper loss} = (E_{tb} - E_{rb})\, i_2$$

$$\text{Secondary efficiency} = \frac{E_{tb} \times i_2 - (E_{tb} - E_{rb})\, i_2}{E_{tb} \times i_2}$$

$$= \frac{E_{rb}}{E_{tb}}$$

IV. Single-Phase Performance—No-Load Rotor Currents

Suppose, now, that with the motor running at synchronous speed, phase A (Fig. 3) be disconnected from the line. The flux ϕ_a and the two e.m.fs. due to it (E_{rb} and E_{ta}) will disappear. The two remaining e.m.fs., E_{tb} in circuit B and E_{ra} in circuit A, will then be left unopposed so that currents will begin to flow in both circuits. It is especially important at this point to note the actions which take place in circuit A. Circuit A surrounds the magnetic path from which, at the instant we are considering, the flux of phase A has disappeared. Until the actions about to be described have been completed, no flux traverses this path.

The e.m.f. E_{ra} will act, therefore, just as an original impressed voltage. A current will flow; a flux, usually called the "cross flux," will appear, and an e.m.f. will be induced. The phase relation of this induced e.m.f. (E_{ta}) will be approximate but not exact opposition to the impressed e.m.f. (E_{ra}), as shown in Fig. 6, which is the ordinary vector diagram of flux e.m.f. and current relations in a simple inductive circuit.

The cross flux occupies the magnetic circuit of phase A and it is therefore cut by the rotation of the B conductors. Consequently, with the appearance of the cross flux, a rotational e.m.f. appears again in circuit B, and the phase relation of this rotational e.m.f. (E_{rb}) to the opposing transformer e.m.f. (E_{tb}) is such as to leave an effective or unopposed e.m.f. in the circuit so that a current will flow.

It will now be shown that at synchronous speed the value and phase relation of the effective e.m.f. in circuit B is such as to make the current exactly equal and at right angles to the

magnetizing current in circuit A. At synchronous speed, transformer and rotational e.m.fs. due to the same flux must be equal and in phase quadrature. The main flux induces in circuit B the transformer e.m.f. E_{tb}, represented by the line $O\,D$ (Fig. 7), and generates in circuit A the rotational e.m.f. E_{ra} represented by the line $O\,C$. Therefore, $O\,D$ must equal $O\,C$ and $C\,O\,D$ must be a right angle. For similar reasons the lines $O\,K$ and $O\,G$ representing e.m.fs. due to the cross flux must also be equal and at right angles. Therefore, the angle $D\,O\,K$ equals the angle $C\,O\,G$ and consequently the triangles $D\,O\,K$ and $C\,O\,G$ are equal.

From the above it is evident that $D\,K$, which represents the resistance drop in circuit B, is equal and at right angles to $G\,C$,

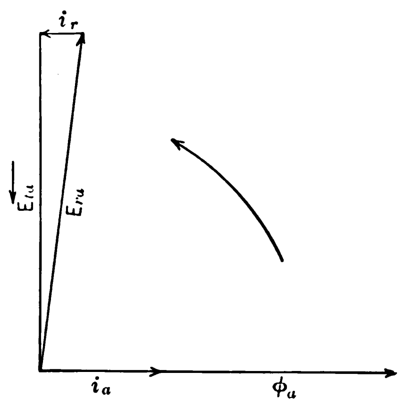


FIG. 6.—REPRESENTS CONDITIONS AT THE INSTANT WHEN E_{ra} IS AT THE POSITIVE MAXIMUM.

All other figures represent conditions, ¼ cycle later, when the impressed e.m.f. in phase B is at the positive maximum.

which represents the resistance drop in circuit A. Therefore the currents also must be equal and at right angles. These no-load rotor currents will be designated i_a and i_b respectively.

The cross field magnetizing current i_a cannot react directly on the primary, since circuit A in which it flows is not in inductive relation with the active primary winding. The current i_b, however, which flows in circuit B—the working circuit of the rotor—reacts on the primary in the same manner as the working current, and as a result of its demagnetizing action, an additional no-load current i_{ms}—represented by the line $M\,S$, Fig. 8—flows in the primary winding. At a speed slightly above synchronism, as will be shown below, the current i_{ms} becomes wattless and is

represented by the line $M V$. The length of the line $M V$, which we shall now proceed to determine, is the first of the three problems enumerated in the opening paragraph.

The lines $O S$ and $M S$, Fig. 8, represent the primary and secondary currents when the motor is running at synchronous speed. The lines $O W$, $E W$, $O Y$ and $D Y$ represent, as heretofore, the hypothetical e.m.fs. corresponding to the primary and secondary currents. As in Fig. 7, which, it will be noted, is reproduced as a part of Fig. 8, $D O$ represents E_{tb}, the resultant or effective transformer e.m.f. in circuit B; $O C$ at right angles to $D O$ represents the resultant main flux and also the rotational e.m.f. in

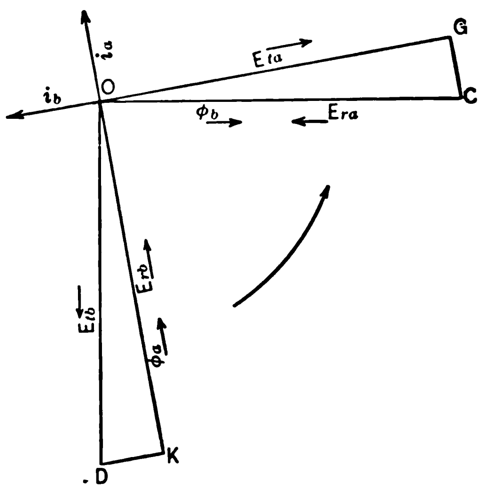


FIG. 7.—REPRESENTS CONDITIONS AT THE INSTANT WHEN THE IMPRESSED E.M.F. IS AT THE POSITIVE MAXIMUM.

circuit A; $C G$ represents the resistance drop in circuit A due to the current i_a; $O G$ represents the transformer e.m.f. in circuit A; $O K$, at right angles to $O G$, represents the cross flux and the rotational e.m.f. in circuit B; while $D K$, the vector sum of E_{tb} and E_{rb}, represents the unopposed e.m.f. which produces the current i_b.

Since the rotational e.m.fs. vary with the speed, it is evident that at slightly above synchronism the value of E_{rb} will be increased to such an extent as to bring $D K$ into exact phase with $O M$. At this speed, as was stated above, $i_{m s}$ will be represented by $M V$. The primary current will then be wattless and the rotor copper loss will be supplied mechanically.

This condition is represented by Fig. 9. At the speed at which the current i_{ms} becomes wattless, that is, when the angle $O\ D\ K$ is a right angle, the cross flux is equal to the main flux, as will now be demonstrated.

Inasmuch as $K\ O\ G$ and $D\ O\ C$ are right angles, it is evident that the angles $D\ O\ K$ and $G\ O\ C$ must be equal, and since $O\ D\ K$ and $O\ G\ C$* are right angles by construction,

$$\cos\theta = \frac{O\ D}{O\ K} = \frac{O\ G}{O\ C}$$

Therefore

$$\frac{O\ D}{O\ G} = \frac{O\ K}{O\ C} \text{ or } \frac{E_{tb}}{E_{ta}} = \frac{E_{rb}}{E_{ra}}$$

and since

$$\frac{\text{rev. per min.}}{\text{syn}} = \frac{E_{ra}}{E_{tb}} = \frac{E_{rb}}{E_{ta}}$$

it follows that

$$E_{ra} = \frac{E_{tb} \times E_{rb}}{E_{ta}} = \frac{(E_{rb})^2}{E_{ra}}$$

and

$$(E_{ra})^2 = (E_{rb})^2$$

$$E_{ra} = E_{rb}.$$

Therefore,

$$\phi_b = \phi_a$$

Further, since the triangles $O\ G\ C$ and $O\ D\ K$ have been shown to have a side and two angles equal and are therefore equal in all parts, it follows that the side $G\ C$, which represents the drop in circuit A, is equal to $D\ K$, which represents the drop in circuit B, and consequently the currents i_a and i_b which cause the drops are equal.

It has now been shown that at the speed at which the current i_{ms} coincides with $M\ V$, the cross flux equals the main flux and

*The assumption that $O\ G\ C$ is a right angle neglects the effect of the cross field iron loss, which reacts on circuit A just as the main field iron loss reacts on the primary. Actually the angle $O\ G\ C$ is slightly larger than a right angle. This fact does not, however, detract from the practical accuracy of the conclusions reached in regard to the value of the current i_{ms}.

the current in circuit B equals the current in circuit A. For this speed the physical conditions which determine the value of i_{ms} may be stated as follows:

The current i_{ms} is the increase of primary current due to the demagnetizing action of i_b; i_b equals i_a; the value of i_a is fixed

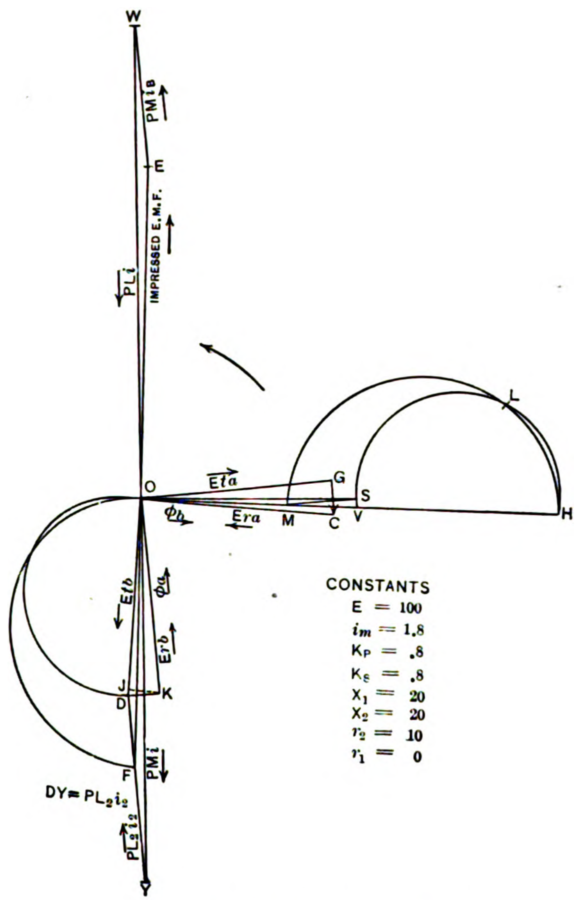


FIG. 8.—SYNCHRONOUS SPEED.

by the fact that it is the magnetizing current which produces the cross flux; the cross flux equals the resultant rotor main flux. Briefly, we have to determine the demagnetizing effect on the primary of a rotor current of such a value as to produce in the rotor core a flux equal to the resultant main flux in the rotor.

From the hypothetical e.m.f. vectors, Fig. 9, corresponding to the currents i and i_b, we find that the effective e.m.f. in the rotor

$$E_{tb} = P\,Mi - \frac{P\,Mi_b}{K_s}$$

The rotor magnetizing current required to produce the flux by which the above e.m.f. is induced,

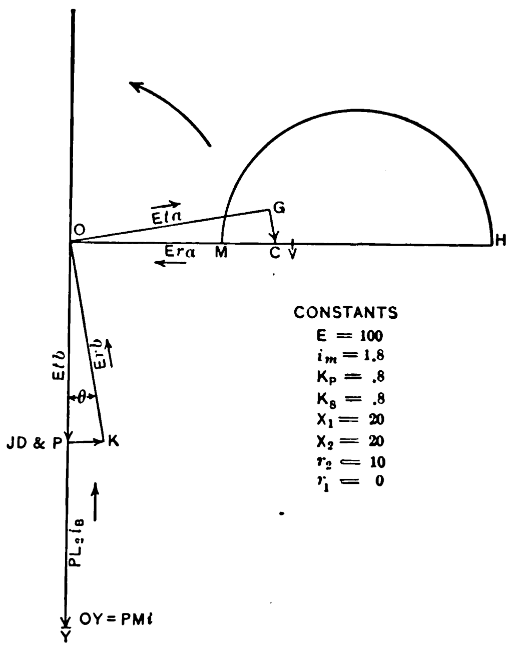


FIG. 9.—THIS FIGURE SHOWS CONDITIONS AT THE SPEED, ABOVE SYNCHRONISM, AT WHICH THE PRIMARY CURRENT IS WATTLESS

$$i_a = \left(P\,Mi - \frac{P\,Mi_b}{K_s}\right) \times \frac{K_s}{P\,M} \quad \text{(equation 6)}$$

$$= K_s i - i_b$$

and since i_a and i_b are equal,

$$i_b = K_s i - i_b$$

$$= \frac{K_s}{2}\, i$$

It has been shown above that the increase of current in the primary due to the demagnetizing effect of a secondary current, equals the secondary current multiplied by K_p.

Therefore,

$$i_{m\,s} = \frac{K_p\,K_s}{2}\,i$$

$$= \frac{K_p\,K_s}{2}\,(i_m + i_{m\,s})$$

$$i_{m\,s}\left(1 - \frac{K_p\,K_s}{2}\right) = \frac{K_p\,K_s}{2} \times i_m$$

$$i_{m\,s} = i_m\left(\frac{K_p\,K_s}{2} \times \frac{2}{2 - K_p\,K_s}\right)$$

$$= i_m \times \frac{K_p\,K_s}{2 - K_p\,K_s}$$

$$M\,V = O\,M\,\frac{K_p\,K_s}{2 - K_p\,K_s}$$

$$= O\,M \times \frac{1 - \dfrac{i_m\,X_1}{E}\,^*}{1 + \dfrac{i_m\,X_1}{E}}$$

It is interesting to note that the value of MV is independent of the secondary resistance.

* When this equation is used in practical work, it is necessary to take account of the fact that i_{ms} is affected less by saturation than i_m, owing the low density of the cross flux in the primary core.

$$\text{If } S\,F\,M = \frac{\text{total ampere turns}}{\text{ampere turns for air gap}} \text{ for main field,}$$

$$\text{and } S\,F\,C = \frac{\text{total ampere turns}}{\text{ampere turns for air gap}} \text{ for cross field,}$$

the complete working formula for $M\,V$ becomes

$$M\,V = O\,M \times \frac{1 - \dfrac{i_m\,X}{E}}{1 + \dfrac{i_m\,X}{E}} \times \frac{S\,F\,C}{S\,F\,M}$$

V. Single-Phase Current Locus

Neglecting the effect of primary resistance, the current locus of a single-phase induction motor is represented by a circle passing through $V\,L$ and H, Fig. 10. That the current locus passes through V and L is obvious, but that it is a true circle and also passes through H, requires demonstration.

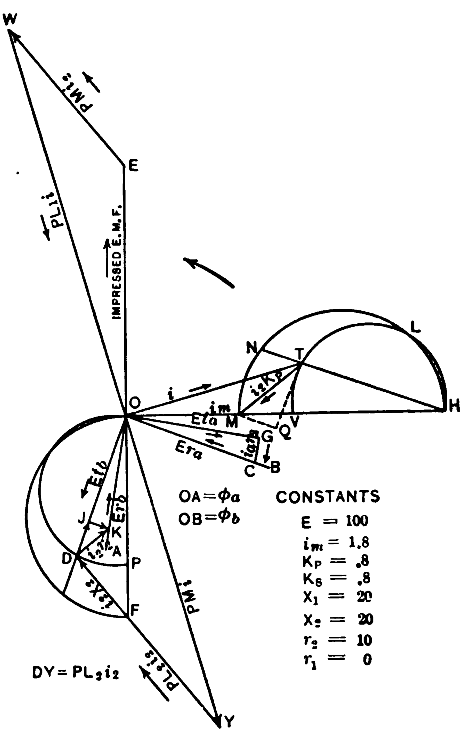


Fig. 10

In constructing Fig. 10, $O\,M$ and $O\,H$ are made equal as in the previous figure to i_m and E/X_1 respectively, and

$$M\,V = O\,M \times \frac{K_p\,K_s}{2 - K_p\,K_s}$$

From any point T on a circle passing through V and L, draw $O\,T$ and $M\,T$ to represent the primary and secondary currents, and lay off, as in preceding figures, the lines to represent the corresponding hypothetical e.m.fs.

At the outset it should be noted that the triangles $F\,D\,O$ and $M\,T\,H$ are similar, each line of $F\,D\,O$ being equal to the corresponding line of $M\,T\,H$ multiplied by the expression

$$\frac{S_1\,X_2}{S_e\,K_p}$$

in which

$$\frac{S_1}{K_p} = \text{secondary amperes per inch, and}$$

$$S_e = \text{volts per inch.}$$

Considering first the lines $F\,D$ and $M\,T$,

$$F\,D\,S_e = I_2\,X_2 \text{ and}$$

$$M\,T\,S_1 = I_2\,K_p$$

$$M\,T\,S_1 \times \frac{X_2}{K_p} = I_2\,K_p\,\frac{X_2}{K_p}$$

$$= I_2\,X_2$$

Therefore,

$$F\,D\,S_e = M\ T\ S_1\,\frac{X_2}{K_p}$$

and

$$F\,D = M\,T\,\frac{S_1}{S_e}\,\frac{X_2}{K_p} \text{ as stated above}$$

Taking next the lines $F\,O$ and $M\,H$,

$$F\,O\,S_e = P\ M\ i_m{}^{*}\text{, and}$$

$$M\,H\,S_1 = (O\,H - O\,M)\ S_1 = \frac{E}{X_1} - i_m$$

$$M\,H\,S_1\,\frac{X_2}{K_p} = \left(\frac{E}{X_1} = i_m\right)\frac{X_2}{K_p}$$

---

*From the similarity of the triangles $O\,W\,E$, $O\ Y\ F$ and $O\,T\,M$, $F\,O$ represents $P\ Mi \times \frac{O\,M}{O\,T}$ which equals $P\ M\,i_m$.

Substituting for X_1 and X_2 the expressions

$$\frac{(1 - K_p K_s) P M}{K_p} \text{ and } \frac{(1 - K_p K_s) P M}{K_s} \text{ respectively,}$$

we obtain

$$M H S_1 \frac{X_2}{K_p} = \frac{E}{K_s} - \frac{P M i_m - K_p K_s P M i_m}{K_p K_s}$$

Substituting

$$\frac{P M i_m}{K_p} \text{ for } E,$$

$$M H S_1 \frac{X_2}{K_p} = \frac{P M i_m - P M i_m + K_p K_s P M i_m}{K_p K_s}$$

$$= P M i_m$$

Therefore,

$$F O S_e = M H . S_1 \frac{X_2}{K_p}$$

and

$$F O = M H \frac{S_1}{S_e} \frac{X_2}{K_p} \text{ as stated.}$$

The above results show that, in length, $F D$ is to $M T$ as $F O$ is to $M H$, and since $F D$ is at right angles to $M T$, and $F O$ is at right angles to $M H$, the triangles $M T H$ and $F D O$ are similar.

Therefore, the line $D O$ is at right angles to $T H$ and equals

$$T H \frac{S_1}{S_e} \frac{X_2}{K_p}$$

In a similar manner it may be shown that $O P$ is proportional to $V H$ and equals

$$V H \frac{S_1}{S_e} \frac{X_2}{K_p}$$

Directing attention now to the e.m.f. and flux vectors, $D O$ represents, as in preceding figures, the resultant induced e.m.f. in the rotor; $O B$, at right angles to $D O$, represents the resultant main rotor flux ϕ_b; $O C$, a section of $O B$, represents the rotational

e.m.f. in circuit A, while $C\,G$ and $O\,G$ represent respectively the resistance drop and the induced e.m.f. in circuit A. $O\,A$, at right angles to $O\,G$, represents the cross flux, while E_{rb}, the rotational e.m.f. in circuit B, is represented by $O\,K$, a section of $O\,A$.

It will be noted that E_{rb} and the resistance drop $D\,K$ are not in phase as they were in Fig. 5. This is one of the main distinctive features of the single-phase induction motor. It is due to the fact that the secondary current $M\,T$ has a component $M\,Q$ which is 90 deg. out of phase with E_{tb} or, in other words, parallel to $T\,H$. The existence of this wattless component in the secondary current is the cause of the difference between the two-phase and the single-phase current locus.

At a speed slightly above synchronism, as was shown on a preceding page, the secondary current in circuit B is wattless and $M\,T$ coincides with $M\,V$. At lower speeds the wattless component of the secondary current is represented by $M\,Q$.

The copper drops, due to the two components of the secondary current, are

$$D\,J\,S_e = T\,Q\,\frac{S_1}{K_p}\,r_2$$

$$= N\,M\,\frac{S_1}{K_p}\,r_2$$

and

$$J\,K\,S_e = M\,Q\,\frac{S_1}{K_p}\,r_2$$

$$= N\,T\,\frac{S_1}{K_p}\,r_2$$

in which S_1/K_p = secondary amperes per inch.

The angle $D\,O\,A$ equals the angle $G\,O\,B$, which is constant, and since $O\,J\,K$ is a right angle by construction,

$$J\,K \propto O\,J$$

At the speed at which $M\,T$ and $N\,T$ coincide with $M\,V$, the line $O\,J$ coincides with $O\,P$. See Fig. 9.* Consequently,

*In Fig. 9, J coincides with D because $O\,D\,K$ is a right angle. D coincides with P because $F\,D$, which represents the secondary reactance drop, being proportional and at right angles to $M\,T$, must coincide with $F\,P$ when $M\,T$ coincides with $M\,V$. Therefore $O\,J$ coincides with $O\,P$.

$$N\,T\,\frac{S_1}{K_p}\,r_2 = M\,V\,\frac{S_1}{K_p}\,r_2 \times \frac{O\,J}{O\,P}$$

$$N\,T = M\,V\,\frac{O\,J}{O\,P}$$

$$= M\,V\,\frac{O\,D - D\,J}{O\,P}$$

Since

$$O\,D = T\,H\,\frac{S_1\,X_2}{S_e\,K_p},\; O\,P = V\,H\,\frac{S_1\,X_2}{S_e\,K_p},\text{ and } D\,J = N\,M\,\frac{S_1\,r_2}{S_e\,K_p},$$

we obtain by substitution,

$$N\,T = M\,V\,\frac{T\,H\,\frac{S_1\,X_2}{S_e\,K_p} - N\,M\,\frac{S_1\,r_2}{S_e\,K_p}}{V\,H\,\frac{S_1\,X_2}{S_e\,K_p}}$$

$$= M\,V\,\frac{T\,H - N\,M\,\frac{r_2}{X_2}}{V\,H}$$

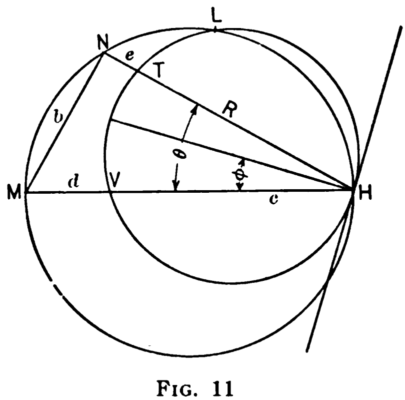


FIG. 11

To simplify the analytical equations which follow, let $e = N\,T$, $d = M\,V$, $R = T\,H$, $b = N\,M$, $C = VH$, $D = M\,H$ and $K = r_2/X_2$

$$e = d\,\frac{R - Kb}{c}\,*$$

$$R = e\,\frac{c}{d} + Kb \quad (9) \qquad \frac{R + e}{D} = \cos\theta \text{ (Fig. 11)} \quad (10)$$

$$\frac{b}{D} = \sin\theta, \text{ and } b = D\sin\theta, \text{ also } e = D\cos\theta - R.$$

*The analytical demonstration which follows is due to Mr. Harold W. Brown.

Substituting in equation (**9**) we obtain

$$R = (D\cos\theta - R)\frac{c}{d} + K\,D\sin\theta$$

$$R + R\frac{c}{d} = D\cos\theta\frac{c}{d} + K\,D\sin\theta$$

$$R\left(1+\frac{D}{d}-1\right) = c\frac{D}{d}\cos\theta + K\,D\sin\theta$$

$$R\frac{D}{d} = c\frac{D}{d}\cos\theta + K\,D\sin\theta$$

$$R = c\cos\theta + Kd\sin\theta \qquad (\mathbf{11})$$

Let ϕ be an angle whose tangent $= Kd/c$, and M the denominator of a fraction such that $\sin\phi = Kd/M$.

Then

$$\cos\phi = \frac{\sin\phi}{\tan\phi} = \frac{\frac{Kd}{M}}{\frac{Kd}{c}} = \frac{c}{M}$$

Dividing equation (**11**) by M we obtain

$$\begin{aligned}\frac{R}{M} &= \frac{c}{M}\cos\theta + \frac{Kd}{M}\sin\theta\\ &= \cos\phi\cos\theta + \sin\phi\sin\theta\\ &= \cos(\theta-\phi)\\ R &= M\cos(\theta-\phi) \qquad (\mathbf{12})\end{aligned}$$

Since R is proportional to the cosine of a variable angle, the curve on which the point T (Fig. 10) lies must be a circle passing through the origin H. (See Cor. 2, Prop. 39, Nichols, Analytic Geom. ed 1893.)*

*Inasmuch as the circle passes through three known points, V, L and H, an expression for the elevation of the center above the base line is not essential. It is easily shown, however, that the elevation of the center above the line $O\,H$ is equal to

$$0.5\,M\,V\frac{r_2}{X_2}$$

From an inspection of Fig. 11, it is evident that the center is above $O\,H$ a distance equal to the diameter $\times$ 0.5 sin ϕ, and also that when R coincides with the diameter θ is equal to ϕ. Equation (**12**) above shows that when θ equals ϕ, M is equal to R, and therefore to the diameter. It follows that:

$$\begin{aligned}\text{Diameter}\times 0.5\sin\phi &= M\,0.5\sin\phi\\ &= 0.5\,Kd\\ &= 0.5\,M\,V\frac{r_2}{X_2}\end{aligned}$$

VI. Revolutions per Minute

Attention has already been called to the fact that at synchronous speed, the rotational and transformer e.m.fs. due to the same flux are equal. That is,

$$E_{ra} = E_{tb}$$

and

$$E_{rb} = E_{ta}$$

(See Fig. 8).

At any speed below synchronous,

$$\frac{\text{rotational e.m.f.}}{\text{transformer e.m.f.}} = \frac{\text{rev. per min.}}{\text{synchronous speed}}$$

Therefore,

$$\frac{E_{ra}}{E_{tb}} = \frac{\text{rev. per min.}}{\text{syn.}}$$

and

$$\frac{E_{rb}}{E_{ta}} = \frac{\text{rev. per min.}}{\text{syn.}}$$

Substituting for the e.m.f. symbols, the e.m.f. vectors of Fig. 10, we have

$$\frac{O\,C}{O\,D} = \frac{\text{rev. per min.}}{\text{syn.}}$$

and

$$\frac{O\,K}{O\,G} = \frac{\text{rev. per min.}}{\text{syn.}}$$

from which we obtain

$$\frac{\text{rev. per min.}}{\text{syn.}} = \sqrt{\frac{O\,C}{O\,D} \times \frac{O\,K}{O\,G}}$$

$$= \sqrt{\frac{O\,K}{O\,D} \times \frac{O\,C}{O\,G}}$$

Since

$$O\,K = \sqrt{(O\,D - D\,J)^2 + (J\,K)^2}$$

we obtain

$$\frac{\text{rev. per min.}}{\text{syn.}} = \sqrt{\frac{\sqrt{(O\,D - D\,J)^2 + (J\,K)^2}}{O\,D} \times \frac{O\,C}{O\,G}}$$

Since

$$\frac{OC}{OG} = \frac{OK}{OJ}*$$

$$= \frac{\sqrt{(OD-DJ)^2 + (JK)^2}}{OD - DJ}$$

we obtain

$$\frac{\text{rev. per min.}}{\text{syn.}} = \sqrt{\frac{\sqrt{(OD-DJ)^2+(JK)^2}}{OD} \times \frac{\sqrt{(OD-DJ)^2+(JK)^2}}{OD-DJ}}$$

$$= \sqrt{\frac{(OD - DJ)^2 + JK^2}{OD\,(OD - DJ)}}$$

It was shown above that

$$OD = TH\frac{S_1 X_2}{S_e K_p}$$

$$DJ = NM\frac{S_1 r_2}{S_e K_p}$$

and

$$JK = NT\frac{S_1 r_2}{S_e K_p}$$

Substituting, we obtain

$$\frac{\text{rev. per min.}}{\text{syn.}} = \sqrt{\frac{\left(TH - NM\frac{r_2}{X_2}\right)^2 + \left(NT\frac{r_2}{X_2}\right)^2}{TH\left(TH - NM\frac{r_2}{X_2}\right)}}$$

If $NT \times r_2/X_2$, which represents the resistance drop due to the wattless component of the secondary current, be treated as negligible, this expression reduces to

$$\frac{\text{rev. per min.}}{\text{syn.}} = \sqrt{\frac{TH - MN\frac{r_2}{X}}{TH}}$$

which usually gives the speed with sufficient accuracy for practical purposes.

*It is assumed here that OGC is a right angle. As was shown above, the effect of cross-field iron loss makes the angle OGC slightly larger than a right angle. The effect on the speed is too small, however, for practical consideration.

VII. Effect of Primary Resistance

In developing the formulas and graphical processes, used in the construction of Fig. 10, the effect of primary resistance has in all cases been neglected. In other words, the induced e.m.f., $O\,E$, has been assumed to be equal to the impressed e.m.f. and constant. The advantage gained by constructing the diagram on this basis is that it gives the diameters of the semicircles, $F\,O$ and $M\,H$, as well as the lines $O\,M$, $M\,V$ and $F\,P$ a constant length. The fact that these lines are of constant length, so that the points M, H, etc. are fixed, renders possible the use of a number of processes, among them the rev. per min. formulas, developed above, which would otherwise be incorrect.

No error or inconvenience results from this method of construction, since the effect of primary resistance can be taken

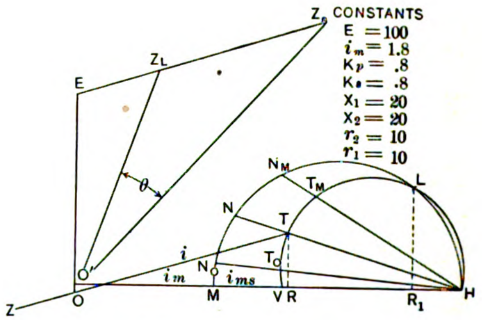


Fig. 12.—Working Diagram.

account of, with all necessary precision, in a very simple manner, as has been shown by De Latour and other writers.

We extend the primary current vector $O\,T$, Fig. 12, to Z, making $O\,Z$ of such a length as to represent the resistance drop due to the current represented by $O\,T$. The vector sum $Z\,E$ represents the impressed e.m.f. which would be required in order to make the induced e.m.f. equal to $O\,E$, and therefore

$$\frac{O\,E}{Z\,E} = \frac{\text{induced e.m.f.}}{\text{impressed e.m.f.}}$$

Correct current values are obtained from the diagram by multiplying each current vector by the corresponding value of $O\,E/Z\,E$

$$\text{primary current} = O\,T\,S_1 \times \frac{O\,E}{Z\,E}$$

and

$$\text{secondary current} = M\,T\,S_2 \times \frac{O\,E}{Z\,E}$$

Also, in determining the secondary input, the fact should be borne in mind that the e.m.f. impressed on the secondary is equal to the e.m.f. induced in the primary, multiplied by K_p, that is,

$$E \times \frac{O\,E}{Z\,E} \times K_p$$

and therefore

$$\text{secondary input} = T\,R\,\frac{S_1}{K_p} \times \frac{O\,E}{Z\,E} \times E \times \frac{O\,E}{Z\,E} \times K_p$$

$$= T\,R\,S_1 \times E \times \left(\frac{O\,E}{Z\,E}\right)^2$$

The value of $O\,E/Z\,E$ must, of course, be separately determined for each value of the current vector $O\,T$.

VIII. Working Diagram

Fig. 12 shows a practical working diagram, based on the analysis of flux, e.m.f. and current relations represented in Fig. 10. If the greatest possible degree of accuracy be desired, the following data, in addition to the line voltage E, are required for its construction.

1. Main field magnetizing current................ i_m
2. Primary leakage coefficient..................... K_p
3. Secondary leakage coefficient.................. K_s
4. Reactance (total reduced to primary)........... X_1
5. Reactance (total reduced to secondary)......... X_2
6. Primary resistance.............................. r_1
7. Secondary resistance (reduced to primary)...... r_2
8. Iron loss due to main field.................... P_{im}
9. Iron loss due to cross field.................... P_{ic}
10. Friction and windage loss...................... P_f

In practical work, however, it is not necessary to distinguish between the values of K_p and K_s. The product

$$K_p\,K_s = 1 - \frac{i_m\,X_1}{E}$$

and sufficient accuracy will be obtained by assuming that either K_p or K_s is equal to

$$\sqrt{1 - \frac{i_m X_1}{E}}$$

If K_p and K_s are equal, it follows from the formulas previously developed that X_1 is equal to X_2. Only one calculation, therefore, is required for reactance. Also, it is not usually necessary to calculate separately the iron loss due to the main and cross fields. It will be sufficiently accurate to make the calculation of the total iron loss just as in the case of the two-phase motor and assign one-half to the main field and the same, or a slightly smaller value, to the cross field.

The quantities, therefore, which it is necessary to determine by previous calculation are

1. Main field magnetizing current.................. i_m
2. Reactance (total).............................. X
3. Primary resistance............................. r_1
4. Secondary resistance........................... r_2
5. Iron loss (total).............................. P_i
6. Friction and windage loss...................... P_f

Let

S_1 = primary amperes per inch

$S_2 = \dfrac{S_1}{K_p}$ = secondary amperes per inch

S_e = volts per inch, for the impressed e.m.f. $(O\,E)$, and resistance drop $(O\,Z)$.

In reconstructing the diagram,

$$O\,H = \frac{E}{X \times S_1}$$

$$O\,M = \frac{i_m}{S_1}$$

$$M\,V = \frac{i_{ms}}{S_1}$$

$$O\,O' = \frac{0.5\,P_i}{E \times S_1}$$

$$O\,E = \frac{E}{S_e}$$

After the above lines have been drawn the larger semicircle should be constructed on $M H$ as a diameter. The locked point L may then be located by making

$$L H = M H \frac{L H}{M H}$$

the factor $L H/M H$ being obtained from the curve Fig. 13. When the location of L has been determined, the smaller circle may be drawn through V, L and H.

The next step is to select a point T for calculation and draw the line $O Z$ of a length equal to

$$\frac{O T S_1 r_1}{S_e}$$

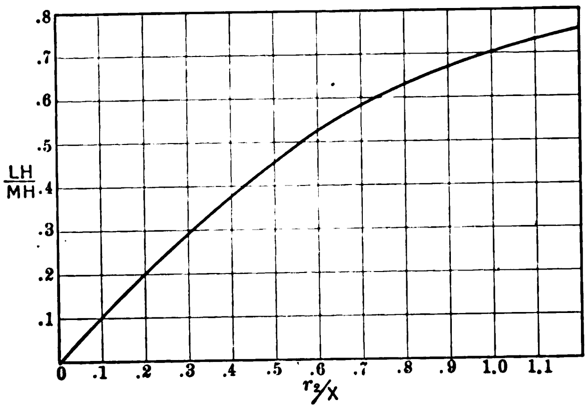


FIG. 13.—CURVE FOR LOCATING LOCKED POINT (L)
$L H/M H$ is the sine of the angle of which r_2/X is the tangent.

In calculating the performance for various values of the primary current, it will be convenient to use a data sheet similar to the one shown herewith. The measurements taken from the diagram are the lengths of the lines $O T$, $M T$, $N M$, $N T$, $T H$, and $T R$, which constitute the first six items on the data sheet, and the length $Z E$ from which ($O E$ being previously known) the ratio of primary induced e.m.f. to impressed e.m.f. may be obtained. This constitutes item No. 7 of the data sheet. When these values for a selected load point have been recorded, the calculation may be completed without further reference to the diagram. The various formulas required are given on the data sheet.

The motor input is equal to the sum of the primary copper loss, the main field iron loss and the secondary input.

The losses fall into two classes,

1. Losses supplied directly by the primary.
2. Losses supplied from the secondary input.

The losses supplied directly by the primary are

1. Primary copper loss.
2. Main field iron loss.

_____H.P._________V. _______~________R.P.M.

$r_1 =$ $r_2 =$ $\frac{i_{ms}}{K_p} =$ $\frac{r_2}{X} =$ $s_1 =$ $s_2 =$ $s_e =$

1	O.T	FROM DIAG.						
2	M T	" "						
3	M N	" "						
4	N T	" "						
5	T H	" "						
6	T R	" "						
7	OE/ZE	" "						
8	MN r_2/X	(3) x r_2/X						
9	NT r_2/X	(4) x r_2/X						
10	TH − MN r_2/X	(5) — (8)						
11	R.P.M.	$\sqrt{\frac{(10)^2+(9)^2}{(5) \times (10)}}$ or $\sqrt{\frac{(10)}{(5)}}$						
12	PRIM. AMPS.	(1) x (7) x s_1						
13	SEC. AMPS.	(2) x (7) x s_2						
14	SEC. C-LOSS A	$\left(\frac{i_{ms}}{K_p}\right)^2 \times r_2 \times \left(\frac{\text{R.P.M.}}{\text{SYN.}} \cdot 7\right)^2$						
15	SEC. C-LOSS B	$13^2 \times r_2$						
16	FE. LOSS CROSS	PREVIOUSLY FOUND						
17	F. & W. LOSS	" "						
18	FE.- LOSS MAIN	" "						
19	PRIM. CU-LOSS	$(12)^2 \times r_1$						
20	SEC. INPUT	$(7)^2 \times s_1 \times E \times (6)$						
21	INPUT	(18) + (19) + (20)						
22	TOTAL LOSSES	(14)+(15)+(16)+(17)+(18)+(19)						
23	OUTPUT	(21) — (22)						
24	TORQUE (OZ-FT.)	(23) x 112.7 ÷ R.P.M.						
25	EFFICIENCY	(23) ÷ (21)						
26	APP. INPUT	(12) x E						
27	POWER FACTOR	(21) ÷ (26)						

DATA SHEET

The losses supplied from the secondary input are

1. Secondary copper loss in circuit *A*.
2. Secondary copper loss in circuit *B*.
3. Iron loss due to the cross field.
4. Friction and windage loss.

At synchronous speed the secondary copper loss in circuit A is equal to

$$(M\ V \times S_2)^2\ r_2 \left(\frac{O\ E}{Z\ E}\right)^2$$

At lower speeds the value becomes

$$(M\ V \times S_2)^2\ r_2 \left(\frac{O\ E}{Z\ E} \times \frac{\text{rev. per min.}}{\text{syn.}}\right)^2$$

The derivation of the other formulas on the data sheet will be evident.

The maximum torque is obtained when the end of the current vector is slightly beyond the center of the arc $V\ L$. The *effective* maximum torque, as determined by a brake test, is usually about 92 per cent of the calculated value.

IX. Starting Torque—Single-Phase Induction Motor with Auxiliary Starting Winding

Neglecting the effect of friction, the starting torque of a two-phase induction motor in ounces at one-foot radius is equal to

$$\frac{225.4 \times P_b}{\text{syn.}}$$

in which P_b is the secondary input from one phase.

The starting conditions of a single-phase induction motor equipped with an auxiliary starting winding differ from those of a two-phase induction motor in two respects.

1. The secondary flux ϕ_s due to the starting winding is not necessarily equal to the secondary flux ϕ_b due to the main winding. Other conditions remaining the same, the starting torque will vary with ϕ_s/ϕ_b.

2. The phase angle θ between ϕ_s and ϕ_b is less than 90 deg. Other conditions remaining the same, the starting torque will vary as the sine of θ.

Therefore the expression for starting torque of a single-phase induction motor is

$$\frac{225.4 \times P_m \times \phi_s \times \sin\theta}{\text{syn.} \times \phi_b}$$

Fig. 14 represents the secondary flux and the currents and induced and impressed e.m.fs. of the main winding and, to a different scale, the same quantities of the starting winding.

If S_1 = amperes per inch for main winding,
then $S_1 \times X_m/X_s$ = amperes per inch for the starting winding, since the same line $O\,H$ represents E/X_m and E/X_s.

The two secondary fluxes ϕ_s and ϕ_b are represented by the same line $O\,B$, while the e.m.f. impressed on the main winding is represented by $O\,Z_L$, and the e.m.f. impressed on the starting winding by $O\,Z_s$. Actually, of course, the impressed e.m.f. is identical in the two cases, both in amount and in phase, and there is a phase displacement equal to θ between ϕ_s and ϕ_b.

When the working diagram, Fig. 12, has been constructed for

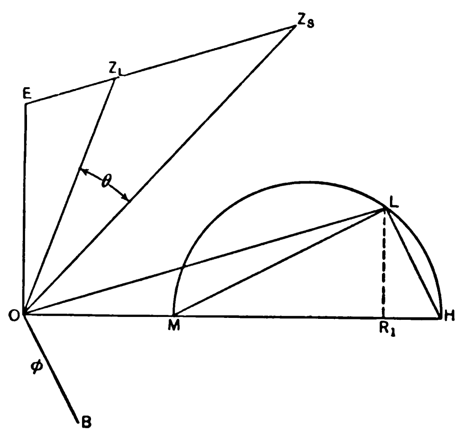


FIG. 14

the determination of running performance, it is only necessary to add the lines $O\,Z_L$ and $O\,Z_s$* to obtain the values which enter into the starting torque formula.

As was shown previously,

$$\phi_b \propto L\,H\,S_2\,\sqrt{X_m} \times \left(\frac{O\,E}{O\,Z_L}\right)$$

*$E\,Z_s$ is parallel to $O\,L$ and equal to

$$\frac{O\,L \times S_1 \times r_{1s} \times X_m}{S_e \times X_s}$$

$$E\,Z_L = \frac{O\,L \times S_1 \times r_1}{S_e}$$

Therefore

$$\phi_s \propto L\,H\,S_2\,\frac{X_m}{X_s}\;\sqrt{X_s}\times\left(\frac{O\,E}{O\,Z_s}\right)$$

Also,

$$\theta = \text{the angle } Z_L\;O\,Z_s$$

and

$$P_m = L\,R_1 \times S_1 \times \left(\frac{O\,E}{O\,Z}\right)^2 E$$

Substituting these expressions in the starting torque formula given above, we obtain

$$\text{starting torque} = 225.4 \times \frac{L\,R_1 \times S_1 \times E}{\text{syn.}} \times \frac{\overline{O\,E}^2}{O\,Z_L \times O\,Z_s} \times \sqrt{\frac{X_m}{X_s}} \times \sin\theta \dagger$$

The effective starting torque is usually about 92 per cent of the calculated value.

X. Comparison of Calculated and Test Results

The results tabulated below were obtained in the course of regular commercial work on motors built to meet special requirements. The reactances and magnetizing currents were calculated by C. A. Adams' formulas and the secondary resistances by DeLatour's formula.

	H.p.	Efficiency		Power factor		Max. torque*		Starting torque*	
		Test	Calc.	Test	Calc.	Test	Calc.	Test	Calc.
1	1	73.5	73.3	71	68.8	144	141	not available	
2	1/2	66.2	66.5	67.1	66.8	70	70	21	21.3
3	1/2	70.4	71	72.6	71.5	49.5	51	not available	
4	1/3	59.5	60.2	66.7	67.5	44.5	44.5	"	"
5	1/12	51	48.6	62.6	64.2	8.1	7.9	"	"
6	1/4	61.6	59.6	64.5	65.6	35	34	23	23.2
7	1/6	56.5	57.7	72.5	75.5	17.25	17.2	16.25	16.6
8	1/6	52	51.8	66.3	65.7	22.4	22.7	14	16.3
9	1/10		63.5		65.6	16.6	16.4	12.25	12.5
10	1/3	64.9	65.8	68.3	67	36.5	35.3	22.2	22.5
11	1/4	61.5	61.7	69	67.2	26	25.4	19	18.3
12	1/12	49	46.8	58.2	62	13.25	11.6	9	9.5

*Calculated values of maximum and starting torques, as given in the table, are the values obtained by the formulas multiplied by 0.92.

† In ounces at one-foot radius.

The larger discrepancies between test and calculated values are due to errors in the calculation of the constants rather than to the diagram. As an illustration of this fact, the running performance of the 1/12-h.p. motor, which appears as the last item in the above list, was re-figured from test constants with the results which follow:

Horse power	Efficiency		Power factor		Max. torque	
	Test	Calc.	Test	Calc.	Test	Calc.
1/12	49	48.7	58.2	59.5	13.25	13.3

Appendix I—Notation

E = impressed voltage.
E_{ta} = transformer e.m.f. in circuit A.
E_{ra} = rotational e.m.f. in circuit A.
E_{tb} = transformer e.m.f. in circuit B
E_{rb} = rotational e.m.f. in circuit B.
$\dot{i}$ = primary current.
$\dot{i}_m$ = magnetizing current for main field.
$\dot{i}_{ms}$ = secondary no-load current as reflected in primary.
$\dot{i}_h$ = primary current with rotor at rest, assuming r_1 and r_2 = 0.
$\dot{i}_2$ = secondary current.
$\dot{i}_{2h}$ = secondary current with rotor at rest, assuming r_1 and r_2 = 0.
$\dot{i}_a$ = cross-field magnetizing current in circuit A.
$\dot{i}_t$ = secondary no-load current in circuit B.
P_b = secondary input from phase B.
P_m = secondary input from main winding.
r_1 = primary resistance (main winding).
r_{1s} = primary resistance (starting winding).
r_2 = secondary resistance reduced to primary.
X_1 = reactance (total reduced to primary).
X_2 = reactance (total reduced to secondary, but assuming a 1 to 1 ratio).
X = reactance (total, either X_1 or X_2, assuming $X_1 = X_2$).
X_0 = reactance with secondary open-circuited.
X_m = reactance of the main winding (total reduced to primary).

X_s = reactance of the starting winding (total reduced to primary).

ϕ_a = flux of phase A, or the cross flux of a single-phase motor, (effective or resultant value in the rotor).

ϕ_b = flux of phase B, or the main flux of a single-phase motor (effective or resultant value in the rotor).

ϕ_s = flux of starting winding (effective or resultant value in the rotor).

$$K_p = \frac{\text{permeance of the mutual path.}}{\text{permeance of mutual and primary leakage paths in parallel.}}$$

$$K_s = \frac{\text{permeance of the mutual path.}}{\text{permeance of mutual and secondary leakage paths in parallel.}}$$

K_r = $K_p K_s$.

M = coefficient of mutual induction.

L_1 = coefficient of self induction of the primary.

L_2 = coefficient of self induction of the secondary.

P = $2\pi \times$ frequency.

S_1 = primary current scale (amperes per inch).

S_2 = secondary current scale (amperes per inch).

S_e = e.m.f. scale (volts per inch).

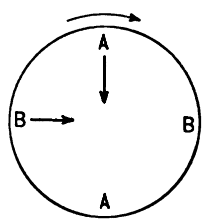
Appendix II—Plus and Minus Signs

All diagrams in this paper are constructed in accordance with the following conventions:

A flux entering the rotor from the top or left is assumed to be positive.

A current which tends to produce a positive flux is assumed to be positive.

A voltage which tends to produce a positive current is assumed to be positive.



From these conventions it follows that:

1. Ohmic drops are of opposite sign to the currents producing them.

2. All voltage triangles of which two sides are opposing induced e.m.fs. and the third side a resistance drop or an impressed voltage, must close without two arrows pointing toward any one angle.

3. When ϕ_a is positive, E_{rb} is positive, but when ϕ_b is positive, E_{ra} is negative, for rotation as per sketch.

Paper presented at the 29th Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June 28, 1912.

EXCITATION OF ALTERNATING-CURRENT GENERATORS

BY D. B. RUSHMORE

THE PROBLEM OF EXCITATION

In order to induce an electromotive force in electrical machinery some sort of excitation must always be provided. In direct-current machines an e.m.f. is induced in the armature conductors by their motion across a stationary magnetic field. This is sometimes also the case with alternators, although it is more usual that the field is revolving, so that the magnetic flux travels past the armature conductors, which are stationary.

In the inductor alternator both the field and armature windings are stationary and only the pole pieces revolve. Due to the varying reluctance of the magnetic circuit, caused by the revolving poles, the flux linked with the armature coils will vary periodically, and induce an alternating e.m.f. in the armature winding. In the polyphase induction motor the stator and rotor currents produce a resultant magnetomotive force resulting in a rotating field which induces e.m.fs. in both the primary and secondary windings. In a transformer, the applied primary current magnetizes the core and produces an alternating magnetic flux which links with both the primary and secondary windings, causing e.m.fs. to be induced therein.

The above cases can in general be divided in two groups: first, those of the transformer action where the field and the windings, in which the e.m.f. is to be induced, are both stationary relative to one another and where the voltage is induced by the alternating magnetic flux; second, those of the generator action, where the field and the windings, in which the e.m.f. is to be induced, move relatively to one another, so that the armature conductors cut the lines of force of the magnetic field.

In this paper it is only the intent to cover that part of the second group which refers to the excitation of alternating-current synchronous generators.

Alternating-Current Generators

Induced E. M. F. An alternating-current synchronous generator is absolutely dependent on a direct-current excitation for its operation, the e.m.f. induced in the armature circuit being determined by the formula:

$$E = 4.44\, k_s\, k_w\, f\, n\, \phi\, 10^{-8}$$

in which

k_s = slot factor.
k_w = winding pitch factor.
f = frequency in cycles per second.
n = armature turns in series per phase.
ϕ = magnetic lines of force.

VALUES OF SLOT FACTOR K_s

Slots per pole per phase	Single-* phase	Two-phase	Three-phase
1	1.000	1.000	1.000
2	0.707	0.924	0.966
3	0.667	0.911	0.960
4	0.653	0.907	0.958
5	0.647	0.904	0.957
6	0.643	0.903	0.956

The values of the winding pitch factor, k_w, are given in Fig. 1.

Characteristics. The field ampere-turns required to produce the magnetic flux which is necessary in order to induce a desired e.m.f. depends on the character of the magnetic circuit, *i.e.*, on its dimensions and on the material of which it is made up. The values are readily obtained by referring to standard saturation curves, similar to the ones shown in Fig. 2, these curves, of course, depending upon the qualities of the iron or steel which is used. The curves are plotted as ampere-turns per inch against kilo-lines per sq. inch, although occasionally ampere-turns per centimeter are plotted against kilo-lines per square centimeter. The total magnetomotive force per magnetic circuit is equal to the sum of the m.m.fs. necessary for establishing the required

*If part of the slots are left open, the breadth of the winding is reduced and the value of K_s is increased to approximately that given for a two-phase winding.

flux in the separate parts of the circuit which are in series, viz., the pole pieces, the field spider, the air-gaps, the teeth and the armature core.

The relation of the e.m.f. produced by an alternator at no-load, *i.e.*, at open circuit, to the field current when the alternator is driven at constant speed is represented by the no-load saturation

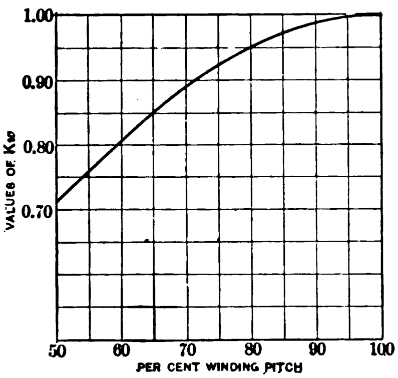


FIG. 1.—VALUES OF WINDING-PITCH FACTOR, K_w.

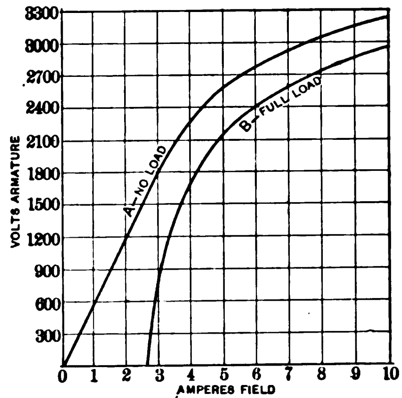


FIG. 3.—ALTERNATOR CHARACTERISTICS.

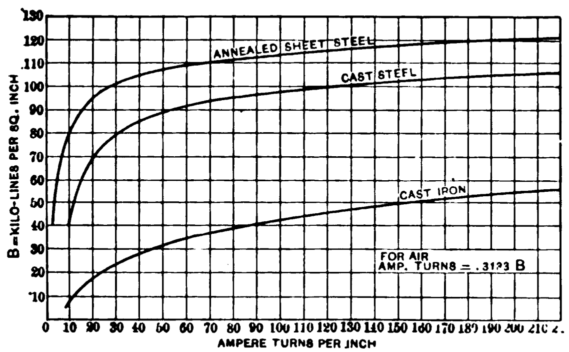


FIG. 2.—SATURATION CURVES.

curve. Such a characteristic curve is shown in curve A, Fig. 3, and it is seen that this curve is almost a straight line for small exciting currents. At low excitation, the reluctance of the air gap is very high and that of the iron very low, and therefore the former may be considered as constituting the entire reluctance of the magnetic circuit. Since the reluctance of air is constant

regardless of the flux density, at small excitations the flux will be proportional to the magnetomotive force, and therefore the open circuit voltage is proportional to the field current, hence the curve is straight. As the field becomes stronger, however, the proportion of the air-gap reluctance to the entire reluctance decreases because the permeability of iron decreases with increased flux density, and therefore the e.m.f. increases less rapidly with increased excitation.

When a current is flowing in the armature circuit, *i. e.*, under load, the field ampere-turns required to maintain normal terminal voltage exceed the no-load ampere-turns required for normal voltage. This is due to the following:

1. The resistance drop in voltage caused by the armature current.
2. The demagnetizing effect of the armature current.
3. The increased leakage flux caused by a greater full-load field excitation.

A number of methods have been proposed for calculating of the above components, and thus determining the total field excitation. A detailed explanation of these methods is, however, beyond the scope of this paper. Knowing the resistance and the leakage reactance of the armature, the voltage drop in the armature is added geometrically to the terminal voltage, and this gives the induced voltage in the machine. Knowing from the no-load saturation curve the required net excitation at this voltage, and correcting it for the effect of the armature reaction, the necessary field ampere-turns are obtained. The result of such calculations for different values of the armature current and for various power factors are represented by the load-characteristic curves. The full-load saturation curve of an alternator is shown by curve B in Fig. 3.

Effect of Power Factor. When the armature current leads the induced e.m.f. in the armature conductors, the armature m.m.f. assists the field m.m.f. and so strengthens the field. When the armature current lags behind the induced e.m.f., the armature m.m.f. opposes the field m.m.f. and so weakens the field.

When the current and the induced e.m.f. are in phase, the two m.m.fs. neither assist or oppose each other, and the influence of the armature reaction is only to distort the main field without changing its value. The current in the armature, however, always lags behind the induced e.m.f. by reason of the inductance, and even with unity power factor in the external circuit the armature reaction is demagnetizing to a certain extent.

The induced armature e.m.f. is proportional to the flux per pole, and thus, with leading current in the armature the induced e.m.f. is greater than the open-circuit voltage, and with lagging current less than the open-circuit voltage. In the latter case, when load is put on the machine the field excitation must, therefore, be increased in order to overcome the armature reaction by an amount sufficient to neutralize the armature demagnetizing magnetomotive force.

Range of Excitation. In order to get the best combination for automatic voltage regulation an alternator should preferably have a range in excitation from no-load to maximum load, with approximately 80 per cent power factor, of the ratio of not more than one to two. With 125 volts excitation, the voltage should therefore not be allowed to exceed 125 volts at maximum load, 80 per cent power factor, and the corresponding no-load excitation should be about 70 volts. Should the excitation voltage be 250, the same ratio should hold true.

Excitation required varies considerably for different machines, depending upon the size, the number of poles, the speed and the regulation. For alternators of different capacities, but otherwise similar, the relative excitation naturally decreases as the size of the alternator increases. High speed machines generally require a less excitation than slow speed, due to the less number of poles. With a large number of poles, however, the air-gap is usually smaller, and this will somewhat offset the higher excitation for slow speed machines.

In general, it may be said that small machines of many poles require a large excitation, and large machines with few poles a comparatively small excitation. The percentage of the excitation of alternators as compared to their output may approximately be taken as from 2 per cent or more for the former class to 0.5 per cent for the latter. In Fig. 4 are given some curves showing approximately the average values of excitation required for different types of alternators.

Exciters

Exciter Characteristics. When exciters are to be operated in connection with automatic regulators it is most important that they be designed with this point in view. The densities, especially in the fields, should be fairly low, as with a high density the time element required to vary the voltage from one point to another would be so long as to materially affect the regulation.

The exciter should preferably have a time element so that it will be responsive to changes in the field excitation to the extent that, by inserting an external resistance equal to about three times the resistance of the field, the voltage will fall from 125 to 25 volts in from four to six seconds. An ideal exciter designed along these lines should also give at full field 165 volts, and the increase in the field current from 125 volts to 150 volts should not be over 50 per cent.

For alternators operating at maximum inductive overload 125 volts is generally required for the excitation, and in order to get satisfactory regulation when a T A regulator is used,

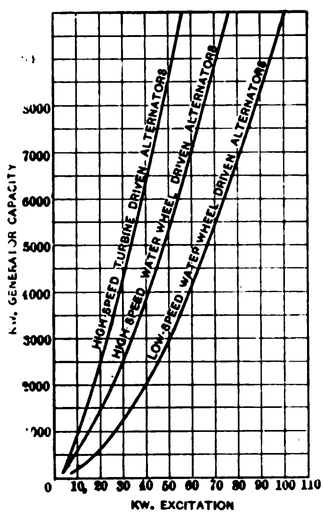


FIG. 4.—APPROXIMATE AVERAGE EXCITATION OF ALTERNATORS.

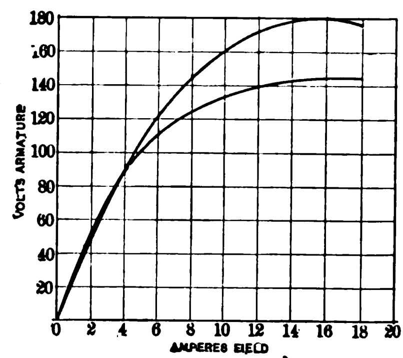


FIG. 5.—SATURATION CURVES OF DIRECT-CURRENT EXCITERS.

the exciter must be designed so as to be able to give 165 volts momentarily. It is also necessary that the increase in the exciter field current should be small, so that the exciter will respond quickly to the short-circuiting of the rheostat, and thus insure the desired alternator excitation. Should the excitation voltage be any other value than 125, *e.g.*, 250 volts, the above values would be proportionally changed.

The curves in Fig. 5 show the saturation curves of two exciters, one representing the characteristics of a machine with a low density, as required, and the other representing the characteristics of a machine with high density and consequently requiring a

large increase in the field current. It can readily be seen that the latter exciter is not as desirable for good voltage regulation as the former exciter when an automatic regulator is used.

The series field excitation should not exceed 30 per cent of the total excitation so that a good regulation may be obtained by control of the shunt field rheostat. In order to obtain the desired variation in the voltage it becomes necessary to provide a rheostat of sufficient size, its resistance being about three times that of the resistance of the exciter shunt field when hot.

Shunt vs. Compound Wound Exciters. While an exciter can be either of the shunt or compound wound type, the latter is preferable. The main reason for this is that a better parallel operation is obtained with compound windings, this being especially true where two or more machines of different size are to be operated in parallel. It makes no difference whether an automatic regulator is used or not, although the series winding loses its value in connection with automatic regulators if the exciters are not operated in parallel.

When operating without automatic regulators, compound wound exciters have the advantage that they will give the same excitation from no load to full load, or they can be slightly overcompounded to take care of the increased load, and will thereby compensate in a measure for the drop or rise in the voltage as the load varies.

Exciters with Commutating Poles. In operating exciters with commutating poles in parallel, there is sometimes a tendency for the incoming machine to take all the load. The reason for this is generally due to the fact that a commutating pole machine, when flat-compounded at 125 volts, has a rising characteristic when operated at voltages less than normal, as shown in Fig. 6. To overcome this it is therefore desirable to flat-compound all exciters with commutating poles at 80 volts, so as to give a drooping characteristic at higher voltages, as shown in Fig. 7.

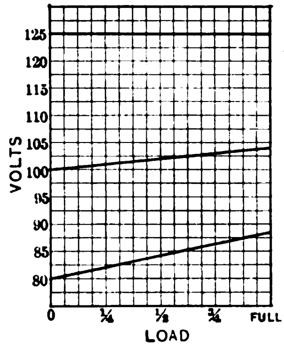
Rating. It is the general practise to so determine the capacity of the exciters that their combined normal rating will correspond to the maximum excitation required for the total generating equipment when operating at the specified power factor.

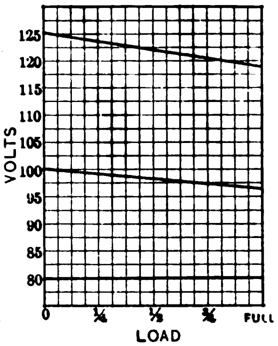
An overload capacity of 25 per cent is therefore generally considered ample to take care of possible excessive load variations and for furnishing current to auxiliary station apparatus and lighting.

The temperature rise at normal load should not exceed 45 deg.

cent. on the commutator and 40 deg. cent. on all other parts; for 25 per cent overload 60 deg. and 55 deg. cent respectively. These temperatures are to be based on thermometer readings, and a room temperature of 25 deg. cent.

Voltage. The pressure most commonly used for excitation is 125 volts. For alternating-current machines of a very large capacity requiring a large excitation it will, however, usually be found to be more economical to use a 250-volt excitation. This higher voltage will necessarily allow a smaller conductor for the exciter and field leads, and in addition the size of the commutator can be considerably reduced, which is important, especially for waterwheel driven exciters where the design must be such as to safely withstand the increased stresses due to a possible double speed.





Figs. 6 and 7.—Compounding of Commutating Pole Exciters.

Speed. The speed of an exciter depends on the method of its drive and on its capacity. Extremely slow or high speeds mean excessive cost with the addition of mechanical difficulties for high speed. This is especially important in hydraulic installations, where the exciters are driven from waterwheels, in which case they must be designed to withstand the increased stresses due to a double speed. This fact should, therefore, always be considered before the speed of waterwheel-driven exciters is fixed.

Mechanical Design. The mechanical design of exciters does not differ from other direct-current generators. They are almost always of the horizontal type, although in certain instances vertical units are desired, due to certain advantages in the

hydraulic equipment. Vertical units are, as a rule, considerably more expensive than horizontal, on account of increased development charges.

The pole pieces are generally built up of laminated steel riveted together and bolted to the frame. The extensions of the pole face serve to hold the field coils firmly in place, and the coils can readily be exchanged when necessary by simply removing the pole pieces.

Belted exciters are generally provided with end shield bearings, as when this type of exciter is selected the required capacity is not very large and two-bearing machines can safely be used. When intended for direct connection to a waterwheel they are almost invariably of the pedestal bearing type, the shaft being provided with the necessary coupling. When, on the other hand, they are intended for direct connection to an engine or to the main generators, shaft and bearings are generally not furnished. In the former case the exciter armature is commonly mounted directly on the engine shaft and the frame is supported on an extension of the engine base, while in the latter case the armature is generally mounted on an extension of the generator shaft and the frame is supported on a bracket outside one of the generator-bearing pedestals.

Vertical exciters are ordinarily provided with one or two guide bearings and a short shaft with coupling. For supporting the revolving element a roller-suspension bearing is sometimes furnished, forming part of the upper bearing bracket. It should be of sufficient size to take care not only of the weight of the exciter armature but also of the revolving element of the prime mover. In certain instances water-wheel builders will furnish a step bearing and if so, guide bearings need only be furnished with the exciter.

Two-bearing belted exciters are usually provided with a sliding base and the belt is tightened by the use of a ratchet screw which moves the machine along the base. When the exciters are rigidly coupled and driven by motors, both the exciter and the motor should be mounted on a common cast iron base to insure perfect alignment.

Pulleys for belt-driven exciters should preferably be of paper, these being preferable to cast-iron pulleys. They are cheaper, lighter and adhere well to the belt. The belt speed should not exceed 5000 ft. per minute and the pulley ratio should not exceed 5 to 1 unless an idler is provided.

Different Methods of Excitation

The excitation of alternators can in general be classified under the following three divisions: *self-excited*, *compositely excited* and *separately excited.* Of these, however, the last named is almost entirely used.

Self-Exciting Alternators. The simplest form of self-excited alternator is the one where the field current is supplied through a rectifying commutator from the armature under consideration.

Self-excited alternators may be divided into series-wound and shunt-wound, depending upon whether the whole current is rectified and led through a comparatively small number of turns around the field magnets, or whether only a portion of the current is rectified and led through a shunt circuit several times around the field poles. Of these, the shunt-wound type has been mostly used, and either the full pressure of the armature, or that of one or more coils, may be impressed directly upon the rectifying commutator, by means of a transformer attached to the armature.

The Alexanderson self-excited alternator is possibly best known in this country. A novel feature of this machine is the automatic voltage regulation accomplished by a special application of the field rheostat. While in ordinary generators the field current is controlled by hand regulation, this machine employs a three-phase field rheostat in which the voltage drop is automatically cut down to the desired extent by a three-phase current forced through the rheostat in opposite directions to the field currents. The current used for reducing the drop in the rheostat is taken from a transformer connected in series with the armature circuit. In this way the field current is regulated with respect to the power-factor as well as to the amount of current taken from the generator.

A diagram showing the general connections of this machine is shown in Fig. 8. The stationary part is provided with two windings, the main winding, *A*, and the auxiliary winding, *B*, which is placed in the same slots as the main winding and consists of a few turns of small wire.

The exciting current is generated in the auxiliary three-phase winding, its terminals being connected to three sets of brushes bearing on a special rectifying commutator. *R* represents three non-inductive resistances connecting the windings to the neutral point. Three series transformers are connected in the main lines of the alternator, the secondaries of which are connected

to the resistance in the *Y*-connection of the auxiliary winding. *F* is the field winding of the alternator, which can be of the ordinary construction. The commutator has one active segment per pole, each alternate segment being connected to one side of the field winding and the remaining segments to the other. By this arrangement it is possible to make the commutation independent of the reactance which is inherent in the ordinary type of field winding, and the whole process of commutation is carried out in the stationary circuits before the current enters the field.

The operation of the machine is as follows: full-load inductive excitation of the machine is obtained from the voltage generated

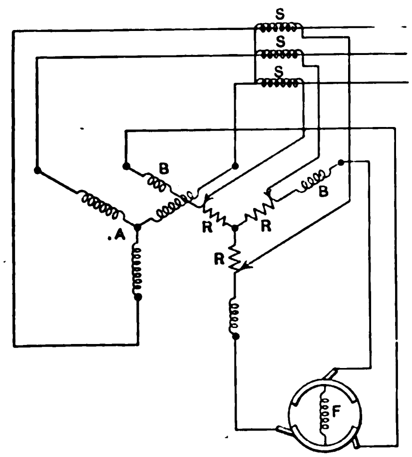


FIG. 8.—DIAGRAM OF ALEXANDERSON SELF-EXCITED ALTERNATOR.

in the auxiliary winding, and the resistance in series with the winding is so adjusted that the current from the winding to the brushes is right at no load. With full-load wattless current of the alternator, the current in the secondary of the series transformer and its potential is such that the drop in the resistance which occurs at no load is completely compensated for, so that there is no potential difference although the resistance is in series with the commutator. With full non-inductive load, since the arrangement of the circuits is such that the opposing e.m.f. by the series transformer is displaced 90 deg. from that generated in the auxiliary winding, the resultant drop in the resistance is of some magnitude and therefore the exciter voltage is less than at full-load wattless current, but more than

at no load. The true relation between excitation at no load, full non-inductive load and full inductive load is illustrated in Fig. 9, in which $A\ B$ is the excitation at full non-inductive load, $A\ C$ the excitation at full inductive load, and $A\ O$, equal to $A\ C - O\ C$, is the no-load excitation. The circle is the locus for the field excitation for different power factors. It is evident that the voltage so obtained at the rectifying commutator is correct for proper compounding, since the relation between the no-load ampere-turns and the full non-inductive load ampere-turns is quite closely found by combining the no-load ampere-turns and synchronous impedance ampere-turns at right angles. This full inductive excitation is very closely obtained, if the no-load ampere-turns and the synchronous impedance ampere-turns are directly added. This corresponds in the diagram to the conditions when $A\ O$ is added to $O\ C$.

Composite-wound Alternators. In order to obtain the result for which compound windings are used with direct-current gen-

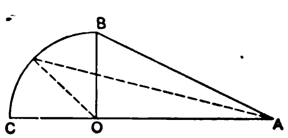


FIG. 9.—EXCITATION DIAGRAM—SELF-EXCITED ALTERNATOR.

erators, compensating windings are used with alternators. The field is excited for its normal open-circuit voltage by an exciter either direct-connected or geared to the generator, while the voltage drop caused by the load current is compensated for by series ampere-turns from self-excitation.

The compensating winding can be connected in many different ways; for example, the armature current may all be rectified for use in excitation, or it may pass through a special transformer attached to the armature, and the secondary of this transformer may supply the current for rectification and self-excitation. Again, the rectified current may be passed through a few turns of wire on each pole, or all the necessary series turns may be placed on one or two poles.

The connections of one type of compensated generator are shown in Fig. 10. There are two collector rings for supplying current to the revolving field, and three collector rings for supplying alternating current from a series transformer to the arma-

ture of the compensating exciter. This set of three rings is mounted outside of the bearing in the case of the smaller belt-driven generators, and inside the bearing, just outside the field collector rings, on the larger belt-driven machines. On the engine-driven generators these rings are mounted on the exciter-shaft.

The compounding of these machines is accomplished by passing three-phase current into the exciter armature in such a way that it reacts magnetically on the exciter field in proportion to the strength and phase relation of the alternating current. Consequently, the magnetic field and hence the voltage of the

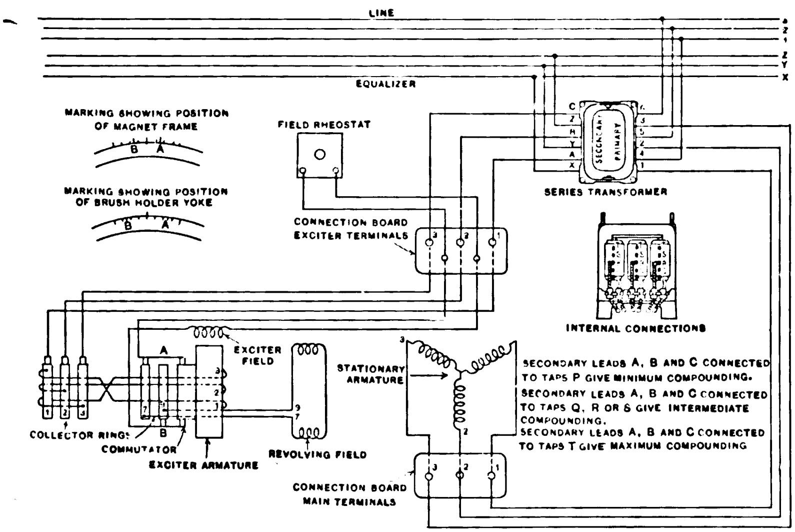


FIG. 10.—CONNECTIONS OF THREE-PHASE COMPENSATED GENERATORS.

exciter are due to the combined effects of the shunt field current and the magnetic reaction of the alternating current. The alternating current passes through the exciter armature in such a manner as to give the necessary rise of exciter voltage as the non-inductive load increases, and without other adjustment, to give greater rise of exciter voltage with additions of inductive load.

An illustration of a compensating generator of the above type is shown in Fig. 11.

Separate Excitation. A separately excited generator has no inherent tendency toward regulation, this either being effected

by a rheostat in the field circuit or by means of different systems of automatic regulator operation, as treated more fully in another part of this paper.

With separate excitation the direct current is obtained by means of exciters, or from some other existing source of direct-current supply or from a storage battery. The first method, however, is the most advantageous and is the one almost invariably used.

Different Methods of Voltage Regulation

Hand Regulation. The simplest system of operation is by means of hand-operated rheostats connected in the field circuits of each generator. The pressure of the exciter bus is then generally kept constant at the rated exciter voltage and all

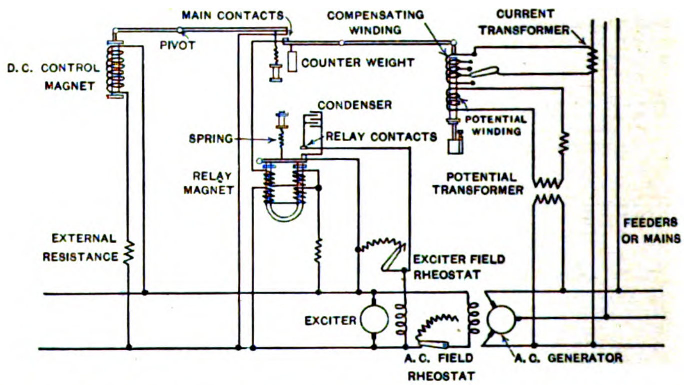
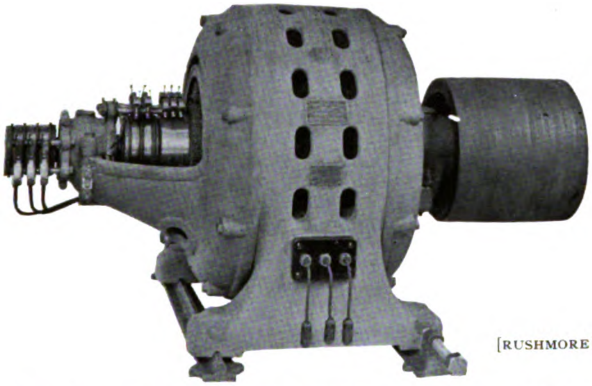


Fig. 12.—Elementary Diagram of Type T A Form A Regulator.

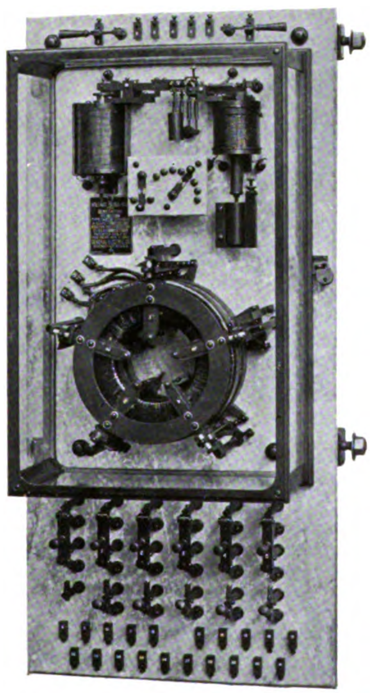
the regulation is done by manipulating the generator rheostats. In order to regulate the exciter voltage it is, of course, also necessary to provide rheostats in the exciter fields.

T A Regulators. Of the various schemes proposed for automatic voltage regulation, the T A regulator is now most widely used. With this system the desired voltage is maintained by rapidly opening and closing a shunt circuit across the exciter field rheostat. The rheostat is first turned in until the exciter voltage is greatly reduced and the regulator circuit is then closed. This short-circuits the rheostat through contacts in the regulator and the voltage of the exciter and generator immediately rise. At a predetermined point the regulator contacts are automatically opened and the field current of the exciter



[RUSHMORE]

FIG. 11.—THREE-PHASE COMPENSATED GENERATOR.



[RUSHMORE]

FIG. 20.—VOLTAGE REGULATOR.

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must again pass through the rheostat. The resulting reduction in voltage is arrested at once by the closing of the regulator contacts which continue to vibrate in this manner and keep the generator voltage within the desired limits.

Method of Operation. An elementary diagram of the type T A, form A regulator's connections with an alternating-current generator and exciter is shown in Fig. 12. The regulator has a direct-current control magnet, an alternating-current control magnet, and a relay. The direct-current control magnet is connected to the exciter busbars. This magnet has a fixed stop-core in the bottom and a movable core in the top which is attached to a pivoted lever having at the opposite end a flexible contact pulled downward by four spiral springs. For clearness, however, only one spring is shown in the diagram. Opposite the direct-current control magnet is the alternating-current control magnet, which has a potential winding connected by means of a potential transformer to the alternating-current generator or busbars. There is an adjustable compensating winding on the alternating-current magnet connected through a current transformer to the principal lighting feeder. The object of this winding is to raise the voltage of the alternating-current busbars as the load increases. The alternating-current control magnet has a movable core and a lever and contacts similar to those of the direct-current control magnet, and the two combined produce what is known as the " floating main contacts."

The relay consists of a U-shaped magnet core having a differential winding and a pivoted armature controlling the contacts which open and close the shunt circuit across the exciter field rheostat. One of the differential windings of the relay is permanently connected across the exciter busbars and tends to keep the contacts open; the other winding is connected to the exciter busbars through the floating main contacts and when the latter are closed neutralizes the effect of the first winding and allows the relay contacts to short-circuit the exciter field rheostat. Condensers are connected across the relay contacts to prevent severe arcing and possible injury.

Cycle of Operation. The circuit shunting the exciter field rheostat through the relay contacts is opened by means of a single-pole switch at the bottom of the regulator panel and the rheostat turned in until the alternating-current voltage is reduced 65 per cent below normal. This weakens both of the control magnets and the floating main contacts are closed. This

closes the relay circuit and demagnetizes the relay magnet, releasing the relay armature, and the spring closes the relay contacts. The single-pole switch is then closed and as the exciter field rheostat is short-circuited the exciter voltage will at once rise and bring up the voltage of the alternator. This will strengthen the alternating-current and direct-current control magnets and at the voltage for which the counterweight has been previously adjusted the main contacts will open. The relay magnet will then attract its armature and by opening the shunt circuit at the relay contacts will throw the full resistance into the exciter field circuit, tending to lower the exciter and alternator

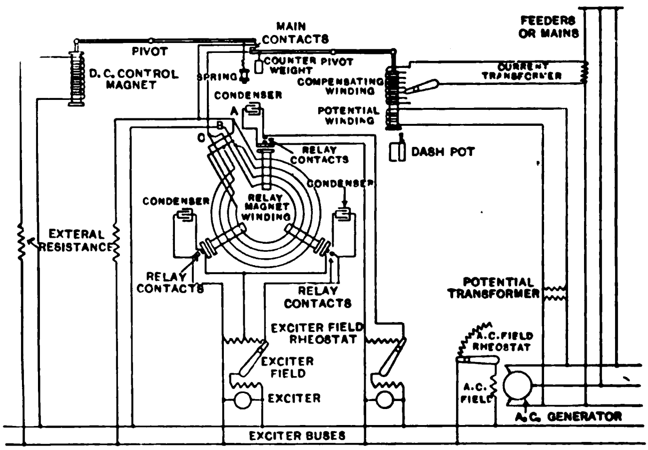


FIG. 13.—ELEMENTARY DIAGRAM OF TYPE T A FORM F REGULATOR CONNECTIONS.

voltage. The main contacts will then be again closed, the exciter field rheostat short-circuited through the relay contacts and the cycle repeated. This operation is continued at a high rate of vibration due to the sensitiveness of the control magnets and maintains not a constant, but a steady exciter voltage.

For larger installations the type T A, form F regulator is generally used, an elementary connection diagram of this type being shown in Fig. 13. This regulator has several relays, varying from two to twelve in number according to the size, capacity and character of the exciters used. While the fundamental principle of operation of these regulators is the same as for the form A, as described above, certain modifications are

necessary in controlling two or more generators. As will be seen by reference to the elementary diagram of the form F regulator, relay No. 1 is connected across the field rheostat of one exciter, while relays No. 2 and No. 3 are placed across sections of the field rheostat of the second exciter. This is necessitated because the second exciter is of larger capacity than the first. Similar modifications are necessary in special cases, but the method of control by the rapidly moving main floating magnets and sensitive control magnets remains identical and maintains the same steady rise and fall in voltage required by the alternating-currrent system.

Compensation for Line Drop. Compensation for line drop may also be obtained with these regulators. For ordinary instal-

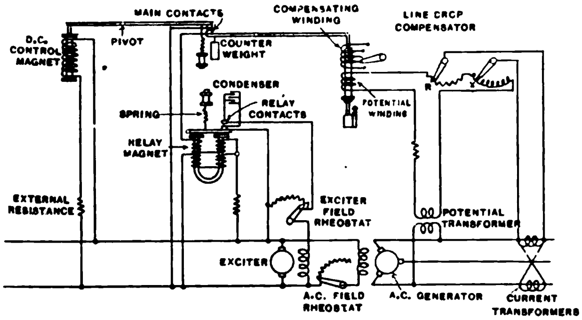


FIG. 14.—CONNECTIONS OF AUTOMATIC REGULATOR FOR ALTERNATING-CURRENT GENERATOR, USING LINE DROP COMPENSATOR.

lations the compensating winding on the alternating-current control magnet is connected to a current transformer in the main feeder. A dial switch is provided by which the strength of the alternating-current control magnet may be varied and the regulator made to compensate for any desired line drop up to 15 per cent, according to the line requirements.

This arrangement is very satisfactory for general use but where the power-factor of the load has a wide range of variation, as in long distance transmission lines, better results can be obtained with a special line drop compensator adapted to the regulator. This compensator, see diagram Fig. 14, has two dial switches with many taps to the resistance and the reactance in the box so that it can be adjusted to compensate accurately for line losses with loads of varying power-factor.

Systems. In larger stations with a number of alternators, the general practice has been to provide two or more exciters operating in parallel and controlled by one common voltage regulator by a suitable arrangement of equalizing rheostats. The connections of such a system are shown in Fig. 15.

A system using T A regulators for preventing cross-currents between generators operating in parallel is shown in the diagram, Fig. 16. This particular arrangement covers two generators operating on separate buses provided with a tie-line. With the tie-switch closed, however, the condition will be the same as if both generators operated in parallel on one bus. One exciter

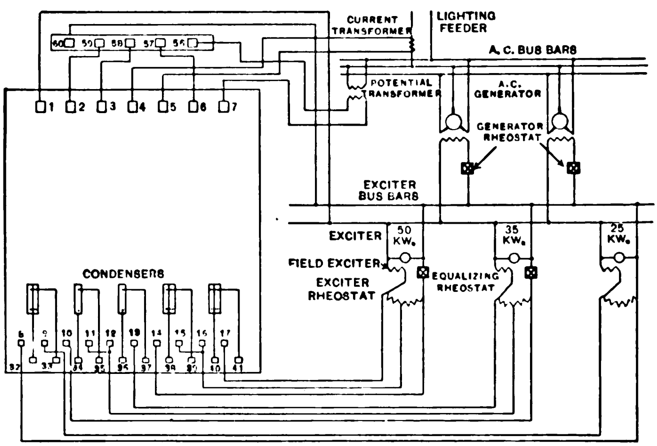


FIG. 15.—ONE ARRANGEMENT OF EXTERNAL CONNECTIONS OF TYPE TYPE T A FORM F REGULATOR.

with its own regulator is provided for each generator, and the current and potential transformers are connected 90 deg. out of phase with each other, so that if cross-currents tend to flow between the generators, the regulator will reduce these cross-currents by strengthening or weakening the field of the generator to which the regulator is connected.

Cut-out Relay. This relay has been devised to be used in connection with T A regulators for guarding against short-circuits and voltage rises in transmission systems. If a voltage regulator is used and a short-circuit should occur somewhere on the system, for example in the transmission lines, the action of the regulator would naturally be to deliver the maximum excita-

tion to the fields of the exciters and generators, so as to keep up the voltage of the system. This in turn necessitates that the governors of the prime movers be wide open, and if the short-circuit should be suddenly relieved, the voltage often rises to

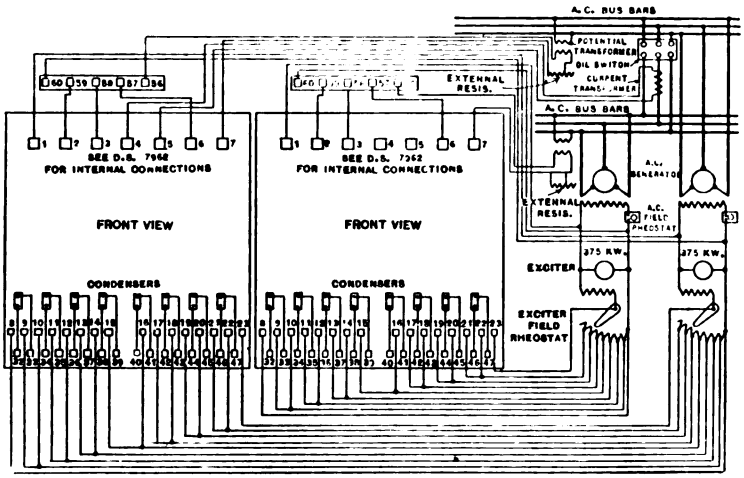


FIG. 16.—CONNECTIONS OF TWO VOLTAGE REGULATORS OPERATING IN PARALLEL WITH ONE ARRANGEMENT OF TWO EXCITERS NOT IN PARALLEL.

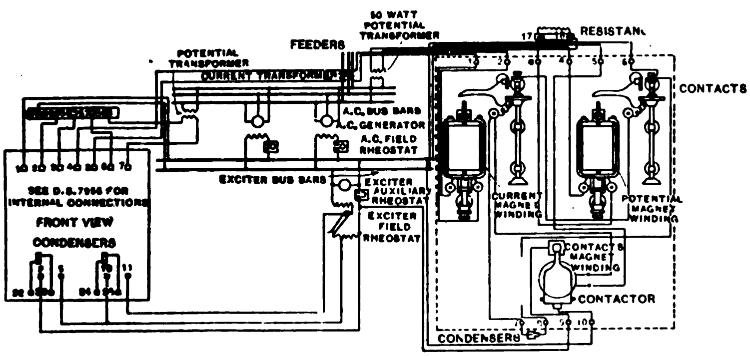


FIG. 17.—CONNECTIONS OF HIGH-VOLTAGE HIGH-CURRENT CUT-OUT RELAY WITH VOLTAGE REGULATOR AND ONE EXCITER.

very high values, owing to the time element involved in closing the governors and in demagnetizing the fields. The connections for a high-voltage, high-current relay operating in connection with one exciter and one T A regulator are shown in Fig. 17. The relay is provided with a current coil and a potential coil,

and will automatically reduce the excitation on the exciters in case of excessive loads, high voltages, or any other cause tending to increase the voltage.

Operating Results. The result of installing T A regulators is shown in the attached charts Fig. 18 and 19, taken before and

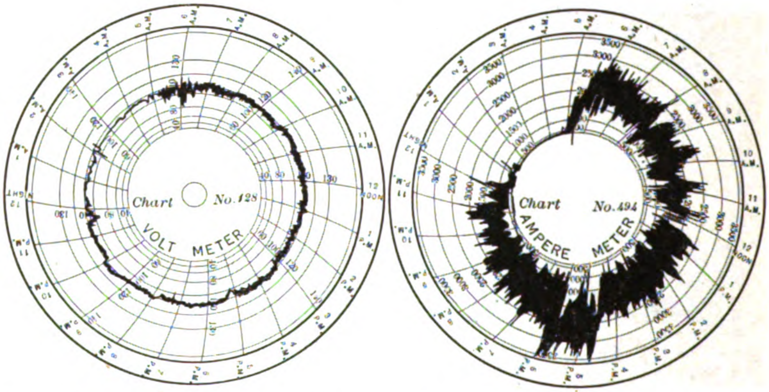


FIG. 18.—CHART SHOWING VOLTAGE REGULATION AND LOAD BEFORE REGULATOR WAS INSTALLED.

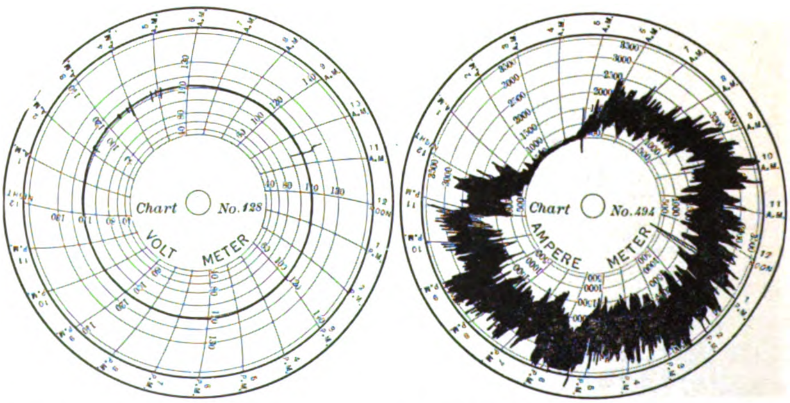


FIG. 19.—CHART SHOWING VOLTAGE REGULATION AND LOAD AFTER REGULATOR WAS INSTALLED.

after the installation of the regulator. With much greater load fluctuations it is seen that the variations in the voltage are practically eliminated by the introduction of the regulator. A view of a type T A, form F regulator is shown in Fig. 20.

The K. R. System of Regulation. This system of regulation

is for use where the excitation for the generators varies considerably, and where at the same time it is desirable to maintain a constant pressure on the exciter busbars, so that current can be taken therefrom for lighting, operation of relays, oil switch mechanisms, etc.

An elementary diagram of this system is given in Fig. 21. By referring to the diagram it is seen that three buses are provided, the upper, which can be called the field bus, while the other may be called the exciter buses. A motor-driven booster is connected across the two upper buses as shown; its object being to boost or buck the exciter voltage and thus vary the voltage applied across the generator fields in proportion to the required

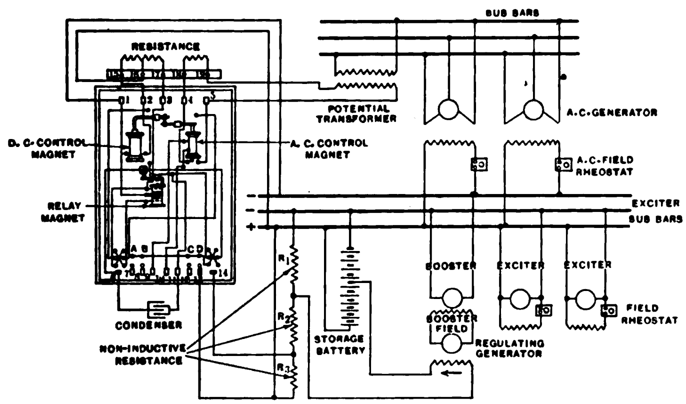


Fig. 21.—Connections of Voltage Regulator with One Arrangement of Two Exciters in Parallel in Conjunction with Storage Battery and Booster.

excitation, without, however, varying the exciter busbar pressure.

The boosting or bucking action of the booster is effected by merely reversing its field, this in turn being accomplished by reversing the field of a small regulating generator or exciter which is direct-connected to the booster. One terminal of the field of the regulating generator is connected to the middle point of a storage battery which is connected across the exciter busbars, while the other terminal of the field is connected to a series of resistances as shown in the diagram, this series of resistances also being connected across the exciter busbars. The connection is made between R_1 and R_2 and a T A regulator is connected across the

terminals of resistance R_3. The object of the storage battery is simply to provide for a neutral point, and a resistance could equally well be provided, although it would not be so efficient. The value of the resistance units are such that $R_1 > R_2$ and $R_2 + R_3 > R_1$.

The operation is as follows: In case the alternating-current bus bar voltage tends to drop, the main contact circuit of the regulator will close, this in turn closing the relay contacts and short-circuiting resistance R_3. As resistance R_1 is greater than R_2, the excitation current for the regulating generator field will flow from the lower bus, through resistance R_2, then through the field and hence through the upper half of the storage battery to the middle bus. This will cause the booster to raise the voltage of excitation, thus increasing the pressure of the alternating bus, until it reaches the value for which the regulator is adjusted. At this instant the regulator main contact circuit opens, thereby opening the relay contacts, thus releasing the short circuit across the resistance R_3. The resistances $R_3 + R_2$, being greater than R_1, will cause the field current of the regulating generator to flow from the lower bus through the lower half of the battery, then through the field and hence through resistance R_1 to the middle bus, thus in opposite direction to which it was flowing before. This will also reverse the booster field, causing it to lower the voltage applied to the generator fields and the alternating-current bus bar voltage will drop.

This action of opening and closing the regulator main contact circuit takes place at the rate of from 300 to 600 times per minute, thereby insuring a perfectly constant voltage across the alternating-current bus bars. If line compensation is desired, it can also be arranged for in the same manner as previously mentioned under T A regulators.

Thury Regulators. The Thury regulator which is generally used in Europe is primarily intended to keep the generator voltage constant by regulating the field resistance. In order to combine rapidity and reliability of action with sensitiveness, the field rheostat is not actuated directly by the fluctuations in voltage but is operated by a small electric motor of about 1/20 h.p., the regulating mechanism being merely brought into play or stopped by the fluctuations of voltage. Fig. 22 is a diagrammatic sketch of the voltage regulator for alternating-current systems, being practically identical with that used in continuous-current installations. *H* is a toothed wheel keyed to the shaft

L which carries the switch arm of the rheostat. *D* is a casting which is rocked to and fro about the shaft *L* by the miniature motor referred to. The pawls *I* and *I'* are attached to *D* in the manner shown, but are held off the toothed wheel by the spring-actuated levers *K* and *K'*. Each of these two levers carries a projection at its upper end; the projection on *K* passes normally above the blade *C*, while that on *K'* rocks to and fro underneath this blade. Consequently, when the blade *C* is lowered or raised in the manner presently to be described, it will strike against *K'* or *K* respectively, thus permitting pawl *I'* or *I* to drop into the teeth of the wheel *H*. The latter is now rotated in the one or the other direction—thus cutting in or

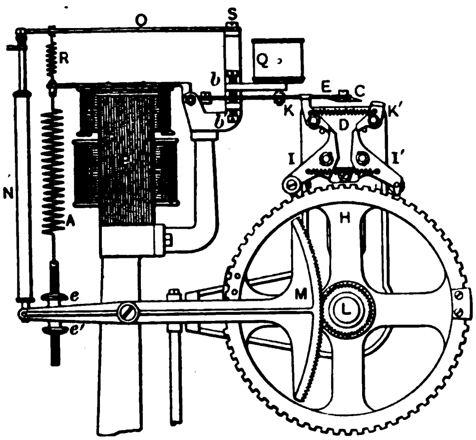


FIG. 22.—DIAGRAMMATIC SKETCH OF THURY REGULATOR.

cutting out field resistance—until the blade *C* regains its horizontal position, when it no longer strikes against *K* or *K'*. Pawls *I* and *I'* are then drawn by spring-action out of contact with the teeth of the wheel *H*.

The electromagnetic mechanism for controlling the position of the blade *C* is as follows: *P* is one of the limbs of the laminations which constitute part of the magnetic circuit through which a flux is maintained by the coil *F*. A very light coil *B*, connected across the bus bars whose voltage is to be controlled, is free to move up or down above *F*, the movement being limited by adjustable stops *b* and *b'*. When the voltage of the supply is normal, the current through *B* is such that the lever *E* carrying the blade *C* is in a horizontal position and nothing happens.

But when the supply voltage is higher or lower than the normal, then a correspondingly larger or smaller current flows through the shunt coil *B*, which rises or falls in consequence and causes the blade *C* to move into the way of the oscillating levers *K* and *K'*, thus actuating the rheostat as previously explained.

The coil *B* moves against the tension and compression of the two springs *A* and *R*, the latter being, in its turn, attached to the free end of a flat spring, *O*, fixed at *S*. The free end of *O* is also in connection, through the intervention of a dash-pot *N*, with the pivoted lever *M*, which takes up a position in accordance with the position of the switch arm by means of the gearing shown. This arrangement tends to steady the removal of coil

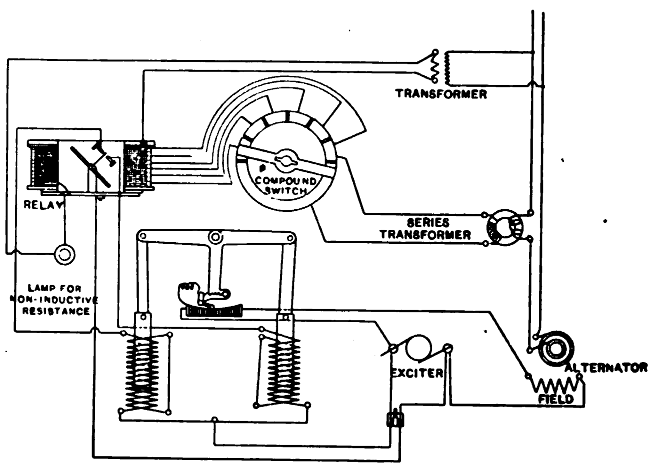


FIG. 23.—DIAGRAM OF CONNECTIONS OF CHAPMAN REGULATOR.

B and to bring it back speedily to its horizontal position after having been deflected. In order to prevent vibrations of the blade *C* in regulators for alternating-current or where the regulation is required to be unusually sensitive, a dash-pot, *Q*, is also provided.

Chapman Regulator. This regulator, a connection diagram of which is shown in Fig. 23, is composed of three distinct parts, viz., a voltmeter, or relay, for detecting small changes of voltage; a rheostat to connect into the field magnet circuit of the generator to be regulated; and a pair of working solenoids to operate the rheostat.

The voltmeter, or relay, consists of a coil of wire wound on a

brass spool. Inside of the coil is a thin iron disk pivoted at opposite ends of its diameter. The tendency of the coil is to move this disk to an angle of 90 deg. with itself, and this force is opposed by a spring, the tension of which is adjustable by a thumbscrew below the coil. The turning of this thumbscrew thus enables one to adjust the voltage of regulation. The disk of the relay has a platinum-tipped spring attached to it which is arranged to make contact with one or another of two platinum-tipped screws and these admit current to one or another of two working solenoids. The platinum points are protected from dust by a metal case with glass top fitting on to the top of the brass spool. A resistance lamp is placed in circuit with the relay coil, the resistance of the lamp being many times that of the coil.

The rheostat part of the regulator consists of a set of resistance units in the smaller sizes of regulator and of cast-iron grids in the larger sizes. The resistance units are connected to a set of contact segments arranged in the arc of a circle on the face of the regulator, and a lever arm carrying the contact shoes moves as a radius to the circle. The contact shoes are pivoted to the lever arm and held in contact with the segments by coil springs.

The lever arm carrying the contact shoes is part of a beam lever that has the cores of the working solenoids pivotally connected to its two ends. These working solenoids are consuming no current except when the regulator is called upon to act, and they are, therefore, in circuit only a small portion of the time. These solenoids have two windings, a primary and a secondary, both wound in the same direction. The primary winding alone is fed with live current, while the secondary has a current induced in it just at the instant of rupture of the contact points, and the induced current, being in the same direction as the live current, prevents the formation of an induction spark at the points of contact, and these points being sparkless will last indefinitely.

An adjustable dash-pot is attached to one side of the apparatus at the bottom. This adjusts the quickness of movement of the regulator to correspond with the characteristics of the generator to be regulated. This dash-pot consists of a brass tube having a spline extending its whole length on the inside. A groove in the piston fits this spline, and whenever the tube is turned it turns the piston also, and opens or closes ports in the piston, which allow a more or less free passage for oil from one side to

the other of the piston. All that is necessary in order to adjust the dash-pot is to turn the containing tube by hand.

The relay of this regulator can be compound wound and may thus be made to compensate for line loss. There is also another way of compensating for line loss which in some instances is more feasible than compounding the regulator, and that is to connect the relay of the regulator directly to a pair of potential wires coming back from the center of distribution.

Booster System. A system used in Europe is shown in Fig. 24. The main feature of this arrangement is a constant exciter busbar pressure, while the voltage for the generator field excitation can be varied by means of varying the excitation of a booster connected in series with the generator field circuit.

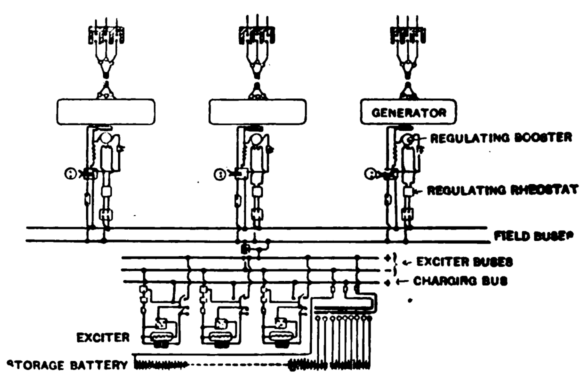


FIG. 24.—REGULATING BOOSTER CONTROL.

The system consists of two or more exciters driven by separate prime movers and adjusted to keep a constant exciter busbar pressure. Their design, however, is such that by manipulating their rheostats a considerably higher voltage than normal can be obtained. This is in order to permit of charging a storage battery, which is done from one of the exciters, this being connected to a charging bus so as not to interfere with the busbar pressure.

In order to vary the voltage across the generator fields one booster regulating generator is provided for and direct-connected to each main generator. It is connected in series with the generator field, and the booster field is also excited from the exciter busbars as shown in the illustration. By reversing and varying the booster field, which is generally done by manually operated

controller, it is possible to vary the field excitation considerably, in one particular instance from 0 to 440 volts, while the exciter busbar voltage is kept constant at 220 volts.

Different Exciter Arrangements

Number of Units. The standard practise for larger stations has in the past been to provide two or more exciters operating in parallel, and of sufficient capacity to excite all the generators in the station. In many installations one or more spare units have also generally been provided as reserve, the number depending on the capacity of the generating equipment.

In some of the recent developments, however, individual exciters are provided for each main generator, each exciter having a capacity sufficient for exciting its own generator only. The exciters are not arranged for parallel operation, but the main generators are generally operating in parallel, being arranged for connection to a common bus, which, however, can be sectionalized if desired.

Method of Drive. Exciters driven by independent prime-movers, either waterwheels or steam engines, are generally found in almost all large installations. While in some modern developments they are used entirely for furnishing the excitation, in others they are generally kept as reserve, and the excitation is normally obtained from motor-driven units. It is obvious that a material saving can be accomplished by reducing the number of exciters driven by separate prime movers to a minimum. This is especially true in hydroelectric developments where the cost of the hydraulic part of such an equipment is very high. Separate pipe lines are preferable for the exciter turbines as the tapping of the penstocks for the main units may seriously interfere with the constant speed of the exciters, due to the fluctuating water supply for the main units, as the load varies.

A view of a station containing two 400-kw. 250-volt vertical waterwheel-driven exciters for exciting a number of large generators is shown in Fig. 25.

Another method of drive is to have the exciters either direct-connected or belted to the main generators. One of the objections to this method is the speed variation of the main units, which naturally also affects the exciters. Another objection is that a trouble in the exciter unit involves the shutting down of the large generating unit. Couplings, etc. can, however, be provided for readily disconnecting the exciter from the main

units, and the generator can be excited from the other exciter units which can be provided with some reserve capacity over what would be required for normal operation. A generator of the horizontal design with a direct-connected generator is shown in Fig. 26, and one of the vertical design in Fig. 27.

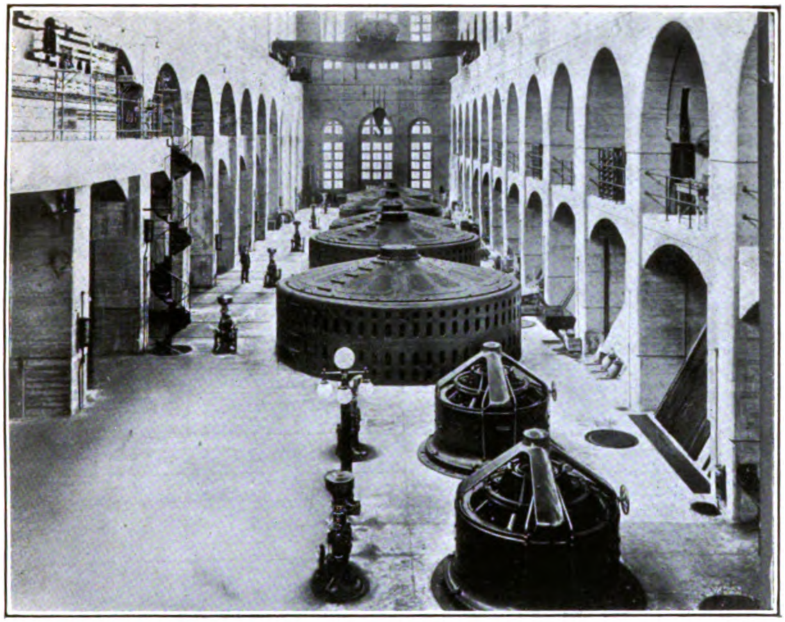
The system which seems to be most generally used is the one where the exciters are driven both by prime movers and motors. While both drives are occasionally used at the same time by coupling the turbine or engine to one end of the exciter and a motor to the other, separate drives are, however, mostly used. In case of the combination method either the prime mover or the motor will have to run idle, unless methods are provided for mechanically disconnecting them from the exciter.

With separate drives enough motor driven exciters are generally provided for exciting the total generating capacity and the exciters driven by prime movers are used as reserve and in starting up the system. This arrangement will therefore give two independent sources of excitation, and in larger stations it might even be advisable to provide two or more exciters driven by prime movers.

In certain of the recent installations one small induction motor driven exciter is provided for each generator, the current for the motors being supplied by separate alternating-current low voltage generators, driven by independent prime movers so as to insure a perfect operation free from fluctuations in speed. Sometimes provision is also made, whereby these auxiliary generators can be driven by motors connected to the main buses, or also whereby the motors of the exciters can be connected through transformers and also fed from the main busbars. A small induction motor driven exciter set is shown in Fig. 28.

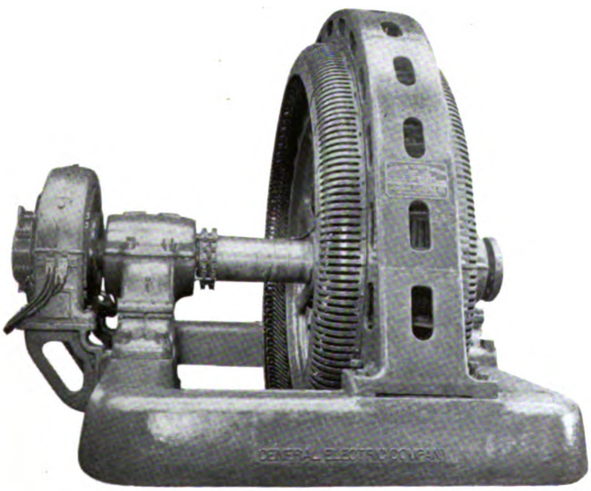
Different Systems of Connection. The system of connections for an exciter equipment varies widely in different installations depending upon the layout of the station, the number of units, the method of drive and other special requirements which must be provided for, such as lighting, storage battery charging, etc. It is therefore difficult to give specific rules for any particular system to be selected, but in the following will be given a description of a number of systems which are in general use.

The diagram shown in Fig. 29 represents a system where three prime mover driven exciters, operating in parallel, are feeding into one common exciter bus extending along all the alternating-current generators. Each generator field is then



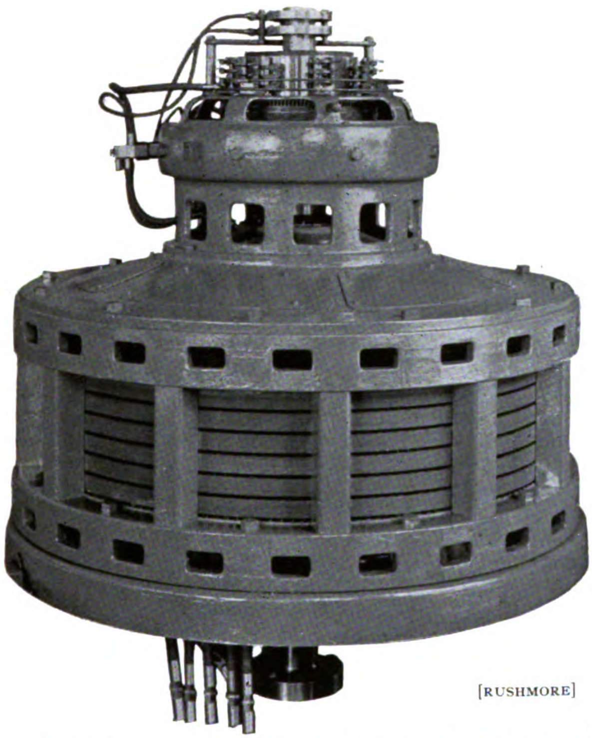
[RUSHMORE]

FIG. 25.—POWER STATION CONTAINING TWO 400-KW., 250-VOLT WATERWHEEL-DRIVEN VERTICAL EXCITERS FOR EXCITATION OF SEVERAL LARGE ALTERNATING-CURRENT GENERATORS.



[RUSHMORE]

FIG. 26.—HORIZONTAL GENERATORS WITH DIRECT-CONNECTED EXCITER.



[RUSHMORE]

FIG. 27.—VERTICAL GENERATOR WITH DIRECT-CONNECTED EXCITER.

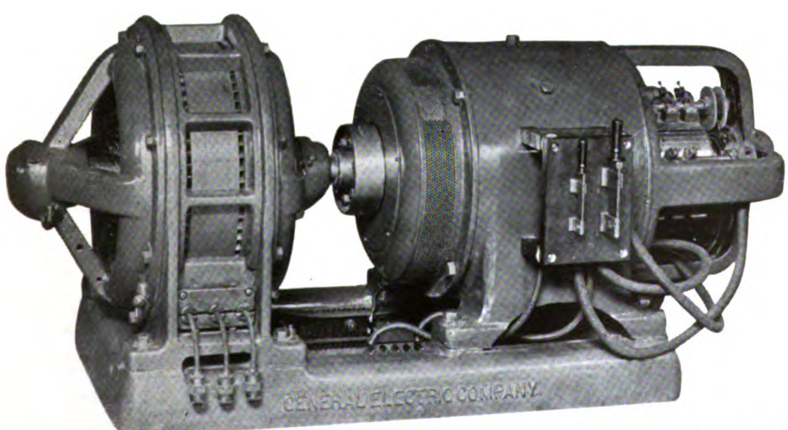


FIG. 28.—INDUCTION MOTOR-DRIVEN EXCITER. [RUSHMORE]

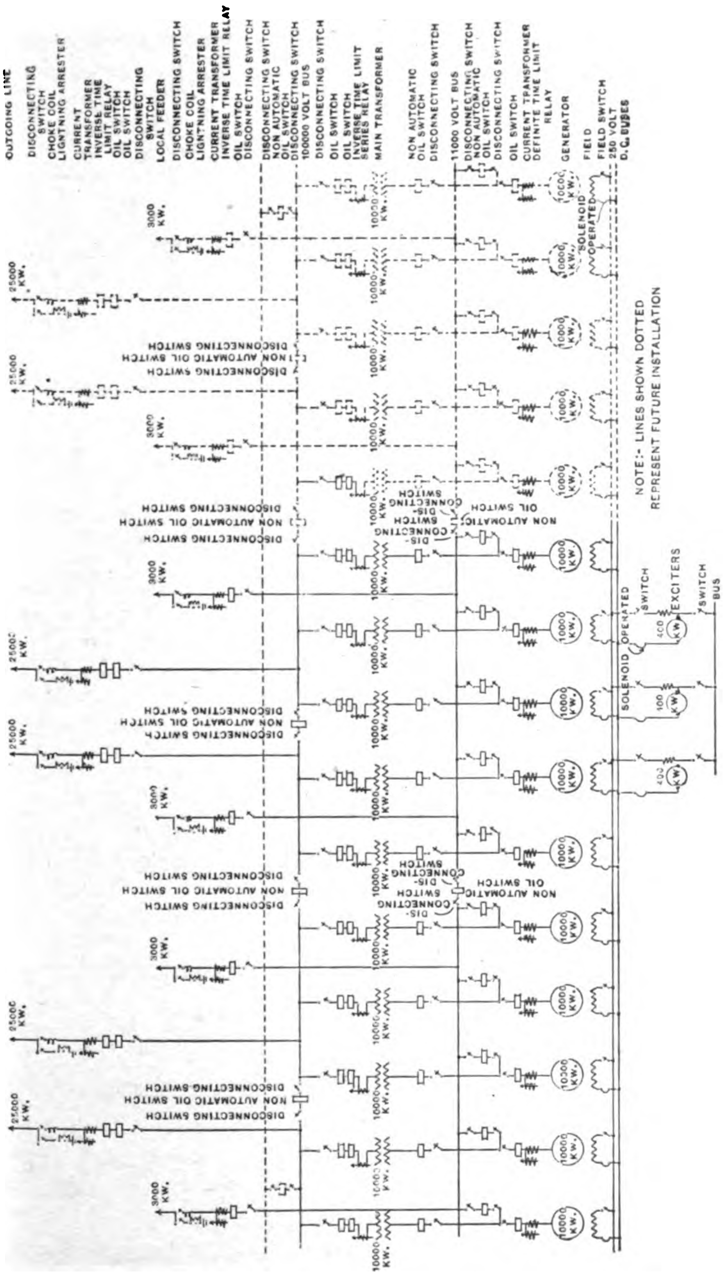


FIG. 29.—SYSTEM OF CONNECTIONS.

connected directly to this bus, the pressure of which is generally regulated by means of automatic regulators, although it can also be done by manual manipulation of the exciter rheostats. In each generator field circuit is also provided a rheostat so that a

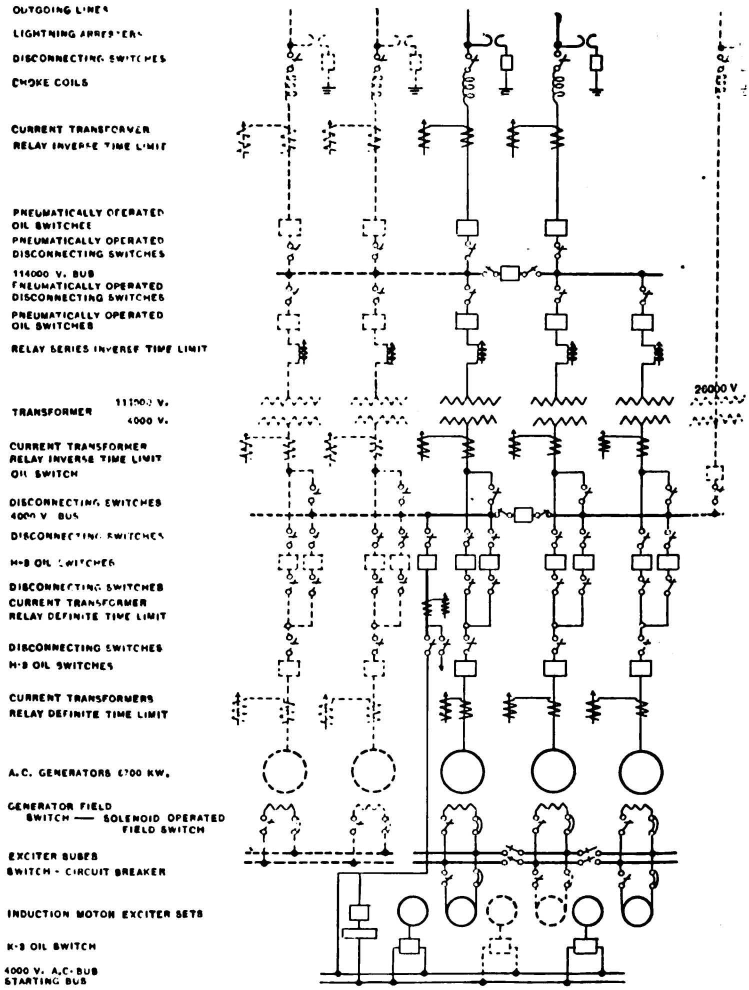


FIG. 30.—SYSTEM OF CONNECTIONS.

separate adjustment of the field excitation for the different generators can be accomplished.

In Fig. 30 are shown the connections of another system in which the exciters are also operating in parallel on a com-

mon excitation, but where they are driven by induction motors fed from the low-tension main bus. Two buses are shown for the motors, one being the running bus and the other the starting bus, the reduced voltage of which is obtained from taps of an auto transformer. In a system of this kind some means must be provided for obtaining direct current when starting up the system. For this reason a small exciter is usually installed, being sometimes driven by a gasolene engine

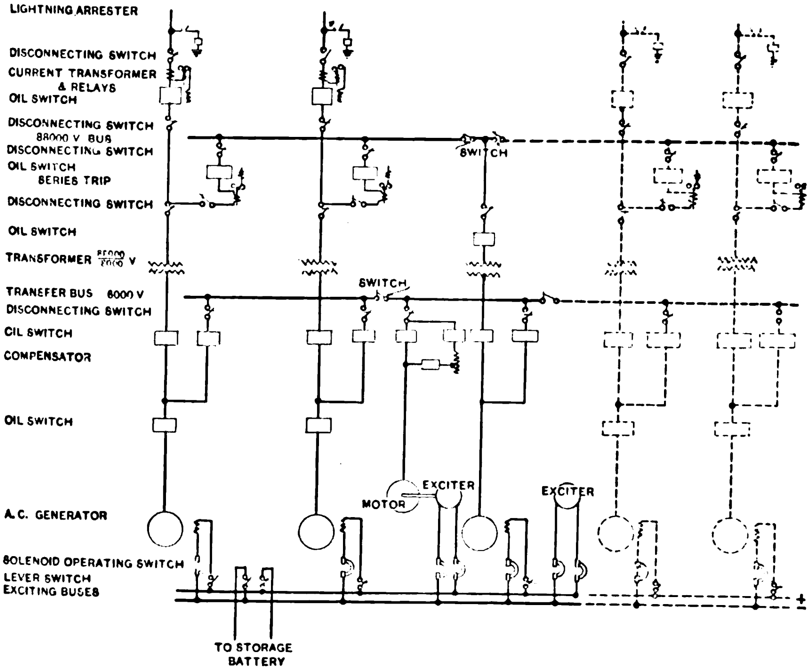


FIG. 31.—SYSTEM OF CONNECTIONS.

or also belted to one of the main units. A storage battery would of course also serve this purpose well.

A system using both a separate waterwheel driven and a motor driven exciter is shown in Fig. 31. The waterwheel driven exciter is then generally used when starting up and for reserve, while the motor driven unit is used for normal operation. Both units can, of course, be operated in parallel if desired.

A system of more flexibility is shown in Fig. 32. Two positive and one negative exciter buses are provided and by means of

double-throw switches it is possible to connect the exciters to either bus and also to excite the generator fields from either bus. If it is desired, two different exciter voltages can be maintained by operating one exciter on either bus. One exciter can also furnish the current for the excitation and the other the current

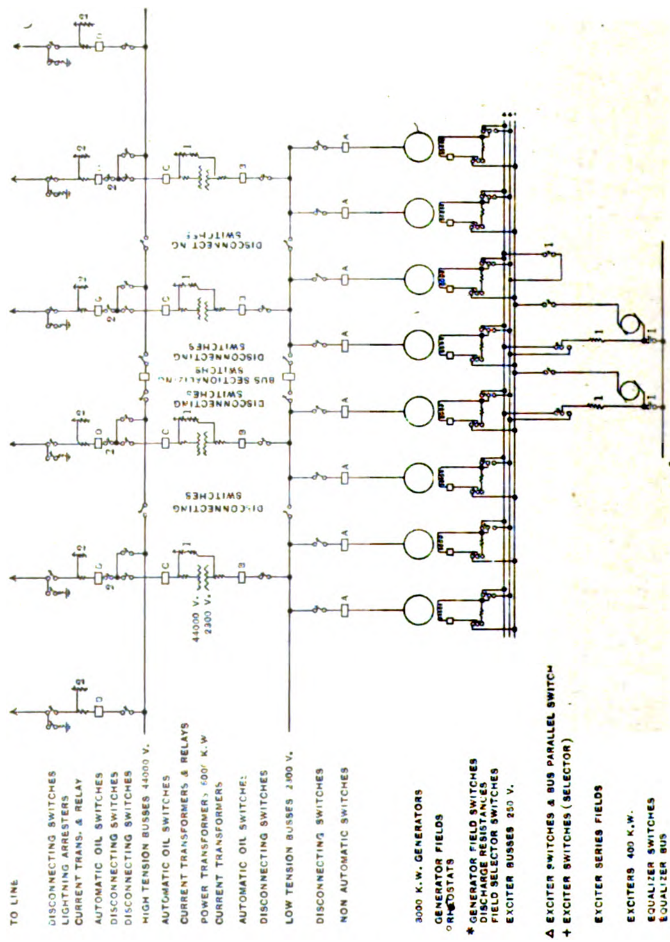


FIG. 32.—SYSTEM OF CONNECTIONS.

for lighting, etc. The fluctuation in the exciter voltage caused by an automatic regulator connected to the first named machine would therefore not be felt on the auxiliary or lighting bus, the pressure of which could be kept constant. A similar arrangement is shown in Fig. 33, with the exception that both sets of buses are double-pole.

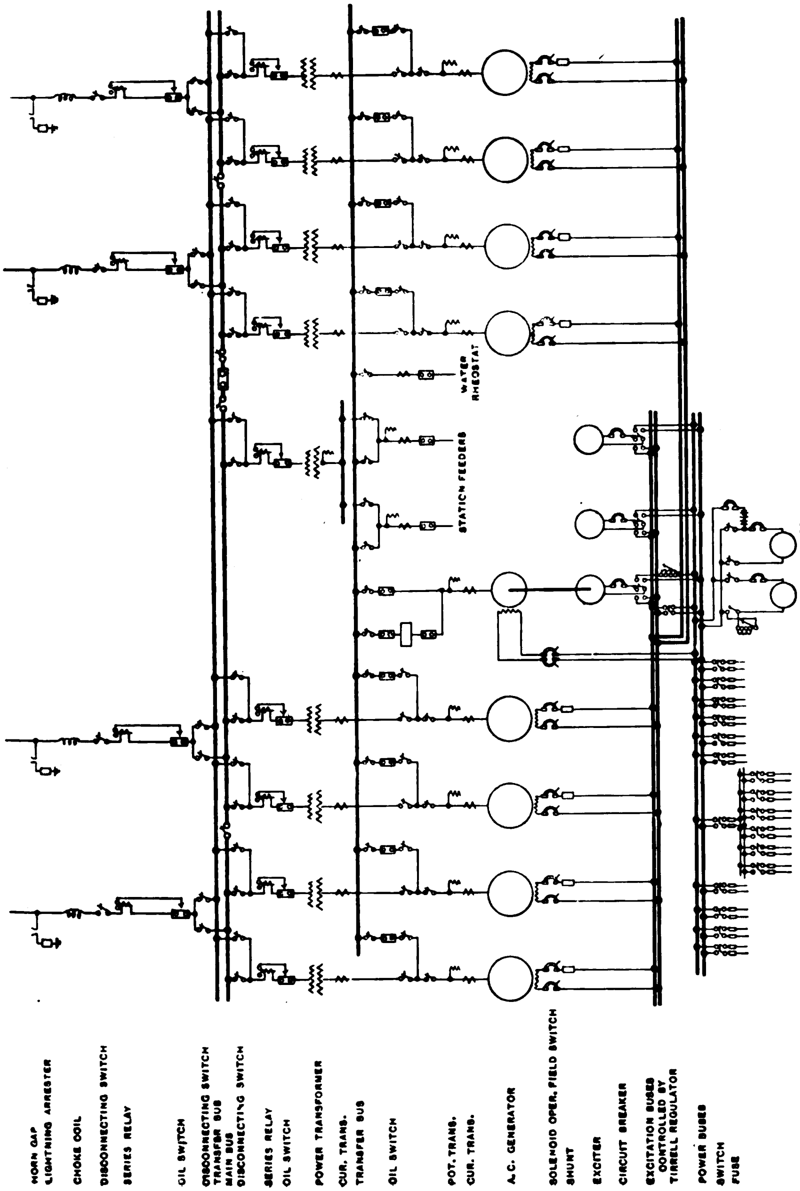


FIG. 33.—SYSTEM OF CONNECTIONS.

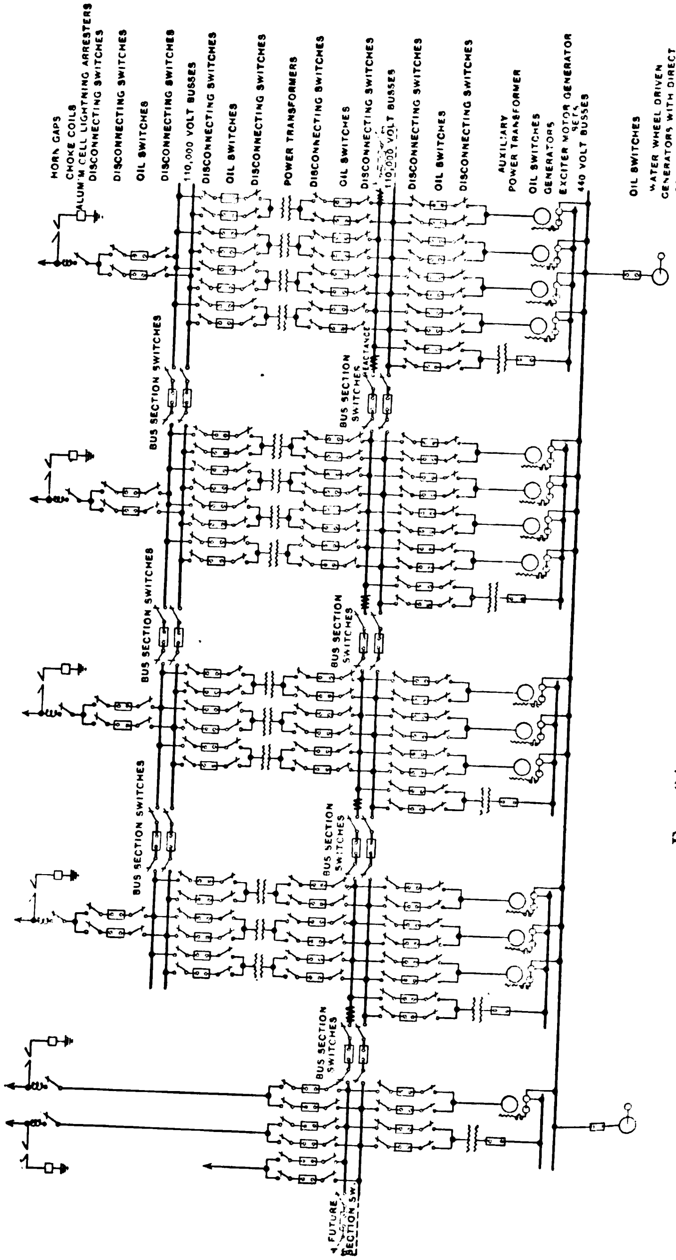


FIG. 34.—SYSTEM OF CONNECTIONS.

In the arrangement shown in Fig. 34 one motor driven exciter is provided for each generator. The exciters are not intended to operate in parallel and one automatic regulator is provided for each exciter. In general, the reason for operating a number of units with the exciters not in parallel is on account of the possibility of an accident. In systems where one or more large exciter units are provided, the operation of a large part of the system may be materially affected if one exciter unit is shut down, while, in the event one of the smaller units becomes disabled, the operation of the system will not be affected to such a great extent.

The possibility of compensating for cross currents between the machines, as previously explained, is also one of the reasons for selecting this system.

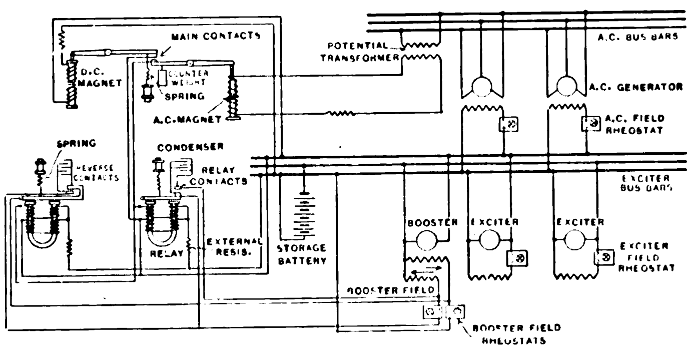


FIG. 35.

The motors driving the exciters are fed either from the main bus or from the two auxiliary waterwheel driven generators, thus giving two independent systems. In another installation, the auxiliary generators are provided with combination drive, *i.e.*, they can be driven either by waterwheels or by induction motors fed from the main buses. In this particular case, however, the individual exciter sets are not intended for being driven directly from the main buses as in the systems shown in Fig. 34.

Storage Batteries. The use of storage batteries in connection with exciters has of late been increasing considerably. The advantages of such a combination are obvious, as, with the failure of the exciters for some reason or other, the storage battery would automatically keep up the excitation. The storage battery is

generally floating on the exciter buses, the pressure of which is kept constant. A separate exciting bus is provided and between this bus and one of the exciter busbars a booster is installed which can be operated to either raise or lower the voltage, its field being controlled by an automatic voltage regulator. The voltage fluctuation is therefore entirely on the exciting buses, being caused by varying the booster voltage by means of the regulator, while the voltage of the exciter busbars is kept constant.

In case of failure of the exciters the excitation would be furnished by the storage battery, and the booster in connection with the regulator would take care of the voltage regulation. Should the booster be disabled, provisions are made whereby it can be short-circuited and the system operated without the regulator.

In the diagram, Fig. 35, are shown the connections of such a system.

The author desires to acknowledge the assistance of Mr. E. A. Lof in the preparation of this paper.

A report presented at the 29th Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June 27, 1912.

INDUSTRIAL EDUCATION

Preliminary Report by the Educational Committee

I. INTRODUCTION

The Institute Committee on Education was reorganized last November as it was impossible for the original chairman to serve. At the meeting held at that time, it was decided to study the status of vocational education, that subject being at the present moment of paramount interest to the industrial interests of the country. The time available has been so short that it is impossible to present more than a preliminary report of progress, but this report may possibly be of sufficient interest and value to warrant future committees of the Institute in continuing the work.

In laying out the plan of procedure of the Committee, no specific effort was made strictly to confine the study to educational conditions as applied to the electrical industries. This attitude was taken because it was believed that the proper establishment of vocational education for *all* children, who cannot advance beyond the rank of hand workers, is essential to the highest success of the country as a whole in its industrial and commercial functions; and, as a result, to the success of the electrical, or any other particular branch of the industries.

It is believed by the committee, since the Institute contains a large and intelligent membership widely distributed over the entire United States, that much good may be accomplished by gathering together in the TRANSACTIONS for ready reference, data which will aid the individual members to effectively influence the development of this most valuable kind of education in their respective commonwealths and communities.

Probably there is no more important problem to be solved by

the industrial communities of this country today than the proper preparation of the new generation for efficient, skilful, intelligent, and loyal labor. It is now quite generally known that we have fallen behind Germany, Austria, France, and some other European nations in this regard. To a certain extent, this is indicated by the fact that many of our exports carry from three to fifteen per cent of labor cost, while a large part of the exports of the countries named carry from forty to eighty per cent of such cost. Indeed, it is not unknown for us to export large quantities of comparatively crude and unmanufactured products to Europe to have them improved and refined by manufacture to many times their original export value and then to have them returned to this country for our consumption. These conditions must to some extent always exist, but the balance against us is so excessive that it behooves us to no longer neglect to take it into consideration.

In regard to the effect of applied education, Mr. H. E. Miles, chairman of the National Manufacturers Association's Educational Committee, makes this statement in a recent report: "By industrial education it now devolves upon us in very important respects to shape the lives of the children of today and thereby to make the men and women of tomorrow. Each year 2,500,000 children graduate from or leave our elementary schools proud and confident in having accomplished the first great task of their lives in successfully finishing the eight years' course with credit. But this same vast army of 2,500,000 little ones, most of them only 14 years of age, leave the schools soon to be discouraged, to prove unsuccessful, aimless; most of them have gotten no further than the sixth grade, having learned little else than the three R's, not educated in any sense, but only possessed of the rudiments whereby real education may be acquired. They then, in a way, learn in school only how to fail. These are the children who come into the industries, and deserve or require industrial or trade education."

This injurious condition, as set forth by Mr. Miles, is to be found to a more or less serious extent in almost every manufacturing community in the United States and, indeed, also to some degree in the rural communities. Such conditions have been largely relieved in Germany by the development of her magnificent system of trade and continuation schools. In this system, after a boy has reached the age of fourteen, he has the opportunity to continue in schools which are particularly adapted by

the character of their teaching and organization to aid him in making himself a skilful and intelligent workman. A compulsory attendance law makes it necessary for most of the boys, whether working or otherwise, to attend these *continuation schools* at least one-half a day per week until sixteen years of age. The expense of the schools is little greater than that required for following the ordinary types of public school curricula with which we are familiar in this country. Though trades are taught,—as many as two score in one of the cities of Germany,—the cost of equipments required is comparatively small; only sufficient apparatus being used to teach the fundamental movements of the process in a particular trade. Because of the large number of pupils who are employed in labor and attend for part time only, these foreign schools cost per pupil, per year, a small fraction of the amount expended per pupil in our best full time trade and industrial schools.

It is considered by well qualified industrialists who have studied the question, that many classes of workmen of continental Europe are more skilful and accurate than similar classes of American workmen, even after due allowance is made for the American's native resourcefulness, energy, and ability. Therefore, if the truth of this statement is conceded, active means should evidently be adopted for the development of educational method which will cause our manual workers of the future to be second to none. This is particularly so since our country must, perforce,— as its population grows and natural resources relatively decrease,—in order to maintain its prosperity, wealth, and the happiness of its people, put forth increasingly greater efforts to maintain its share of the world's enormous trade.

Here, with the exception of a comparatively few successful experiments with continuation and free vocational schools such as are to be seen here and there scattered over the country, as yet comparatively little has been either attempted or accomplished in the form of publicly supported training of the character demanded; and a beginning only has been made in the establishment of industrial schools supported by private benevolence, or by industrial corporations for preparing workers for the ranks of their own employees. The number of pupils enrolled in such schools, the number of teachers employed, and the buildings and equipments in use are small compared with those in some of the European nations. Statisticians estimate that only from

ten to twenty per cent of the children of this country of the age of sixteen whom necessity drives from school to work, are so situated that they can learn a trade. The remainder work at casual employment or in such places as fail to develop their full values to their communities. This condition of inefficiency usually remains with them throughout life to their detriment, and to a considerable degree the character of our export trade is undoubtedly influenced thereby.

It seems probable that this country could, without heavy burden beyond that incurred in maintaining the present more or less inflexible public school system, so modify the pedagogical methods in use as to make it possible for the great majority of sound children to take positions in the world of labor where they could be classed as skilled. Such training of the mass of the people should lead to increased sense of responsibility, good spirit, orderliness, and efficiency and should go far toward removing much of the unrest and dissatisfaction rapidly becoming prevalent everywhere.

On account of the limited time at the committee's disposal, it was decided to study certain schools in the New England and Middle States,—the thought being that if the work is continued by future committees, a further study can be made of the conditions in other parts of the country. Even in the districts chosen it was found wise to confine attention to but a few of the most typical schools and to neglect many institutions of great merit. The work of gathering data was divided among the membership of the committee somewhat as follows: Professor H. H. Norris, of Cornell University, one of the members of the committee, undertook the burden of reporting upon certain schools to be found in New England and New York, adding thereto, with some assistance from the Chairman, descriptions of various schools maintained by the railroad systems of the country. Professor Samuel Sheldon of the Brooklyn Polytechnic Institute was assigned certain typical schools in New York City. Dr. C. P. Steinmetz, of the General Electric Company and Union College, was asked to report upon the methods of development which seemed most desirable to be maintained by electrical manufacturing corporations.

Insomuch as education of this kind, to serve the entire population of the country, must eventually be supported largely from the public purse, and insomuch as many of the commonwealths of the Union are now endeavoring to inaugurate such

work by the enactment of special laws relating to the subject, a special section of the committee's report is devoted to a study of the laws already in existence. Dr. W. I. Slichter, of Columbia University, was assigned the duty of making an investigation of this subject and preparing a brief report thereupon.

It is hoped that the short descriptions of the few schools that are named hereafter and, also, the brief discussion of laws which seem to be suitable for the establishment of effective vocational educational systems, may be of service to members of the Institute, who have not given the subject special study, in aiding them to direct the development of this important phase of education in their own commonwealths. The committee, of course, does not pretend that its findings are complete, or that its data are more than a small fraction of that which is desirable.

Before proceeding with the more detailed discussion, it seems well to point out here certain salient classifications and facts concerning industrial schools. The schools may properly be divided into three classes, namely:

1. Those maintained at public expense and open to all children of their respective districts.

2. Those maintained through private benevolences and also open largely to children of their districts.

3. Those maintained by corporations for preparing skilled employees for their own purposes.

These schools, without including those that are giving drawing, manual training, etc., for purposes of general training rather than for direct vocational preparation, are frequently divided into two types, namely:

a. Full time schools.

b. Continuation schools.

In the former, the youth attends the school continuously until he has been prepared so far as possible, both mentally and manually, for the particular trade or vocation which he proposes to enter. The continuation schools are those to which pupils, already at work, give only part time,—such as evenings, or a day or part of a day each week. The third general division named above consists of continuation schools, while the first and second divisions include both types, or a combination of the two.

In general it may be safely stated that the continuation school in which the pupil, already regularly employed, gives a part of the working hours each week to school work, shows dis-

tinct and positive signs of being best suited to the conditions facing the great majority of young men.

These schools, whether maintained at public expense or by industrial corporations, should aim to develop the mental judgment and physical skill required for promoting the industries in the localities in which they are situated. This means very close correlation between the school work and the shop work in which the youth is engaged, and as a result demands efficient cooperation between the school and shop staffs.

Continuation schools need not be materially more expensive than the common schools, as the practical applied part of the training can be to a large extent obtained during the portion of the time the pupils are at work.

Experience with laws relating to the organization of industrial schools (continuation and full time), carried on at public expense, seems to indicate that certain more or less well defined conditions of organization are desirable. Some of these, which appear to be of especial importance, are presented below for consideration:

1. Young men who leave common schools at fourteen years of age should be expected to spend at least two years thereafter in either a continuation or full time vocational school. Those leaving at fifteen should give at least one year to work of the same kind.

2. Opportunity should be given all residents of the community over fourteen years of age to enroll in the continuation school, upon the payment of a small tuition fee, especially those persons between the ages of fourteen and twenty-five.

3. Each commonwealth should have a commission composed of representatives of the industries, with power to direct the industrial school work of its state, under the condition that its actions are subject to the approval of the regular State board of education.

4. Local communities should have commissions selected from the personnel of the local industries, with power to direct the work of the local industrial schools, but subject in their actions to the approval of the local school boards.

5. The commissions named above need not interfere with the regular public school organization of the state, but should be correlated therewith.

6. In order to encourage the establishment of vocational schools, and to give a proper central authority over the school officials of local communities, the state should give material finan-

cial aid to those institutions which comply with its regulations and are approved by its commission on industrial education.

Lack of state and local boards, whose personnel is drawn from the officials and ranks of the industries, having sufficient power to enforce the adoption of their methods, must as a rule, cause industrial schools to fail to give the full possible measure of usefulness. The modern school teacher usually knows his particular business; but this does not include, in general, the direct preparation of his pupils for industrial pursuits, nor can he have the opportunity to learn the requirements essential to giving such preparation, except through close contact with, and the active cooperation of, the industrialists who are to absorb his pupils into their ranks of labor.

The term vocational education is used in this report to cover any kind of education that leads to a vocation; industrial education is included in this and refers to the bulk of the manual vocations other than agriculture or the domestic arts.

II. PROVISION BY LAW FOR VOCATIONAL TRAINING IN THE UNITED STATES

A survey of the educational enactments of the various states shows that 24 states have active provisions for vocational training, six have permissive provisions and fifteen have no provision at all. In twenty of the States vocational schools are in practical operation.

Massachusetts, Wisconsin, New York and Maine seem to have given the subject the most careful consideration and special commissions to study the subject have rendered elaborate reports on the subject. The State of Massachusetts seems to be not only the pioneer but the leader in this branch of education and while other states may have studied the subject and made provisions for the training yet Massachusetts is the only state in which elaborate provisions are in actual operation. As the term vocational training is used in a very broad sense and includes any training intended to prepare the scholar to become economically productive, it is desirable to distinguish between the various forms of training to be discussed. The amended acts of the State of Massachusetts carefully define the various forms of education as follows:

1. "Vocational education" shall mean any education the controlling purpose of which is to fit for profitable employment.

2. " Industrial education " shall mean that form of vocational education which fits for the trades, crafts and manufacturing pursuits, including the occupations of girls and women carried on in workshops.

3. " Agricultural education " shall mean that form of vocational education which fits for the occupations connected with the tillage of the soil, the care of domestic animals, forestry and other wage-earning or productive work on the farm.

4. " Household arts education " shall mean that form of vocational education which fits for occupations connected with the household.

5. " Independent industrial, agricultural or household arts school " shall mean an organization of courses, pupils and teachers, under a distinctive management, approved by the board of education, designed to give either industrial, agricultural or household arts education as herein defined.

6. " Evening class " in an industrial, agricultural or household arts school shall mean a class giving such training as can be taken by persons employed during the working day, and which, in order to be called vocational, must in its instruction deal with the subject-matter of the day employment, and be so carried on as to relate to the day employment.

7. " Part-time, or continuation, class " in an industrial, agricultural or household arts school shall mean a vocational class for persons giving a part of their working time to profitable employment, and receiving in the part-time school, instruction complementary to the practical work carried on in such employment. To give " a part of their working time " such persons must give a part of each day, week or longer period to such part-time class during the period in which it is in session.

8. " Independent agricultural school " shall mean either an organization of courses, pupils and teachers, under a distinctive management, designed to give agricultural education, as hereinafter provided for, or a separate agricultural department, offering in a high school, as elective work, training in the principles and practise of agriculture to an extent and of a character approved by the board of education as vocational.

9. " Independent household arts school " shall mean a vocational school designed to develop on a vocational basis the capacity for household work such as cooking, household service and other occupations in the household.

Practically all states offer vocational education in the state

normal and training schools for teachers, and work of a collegiate grade in the state land grant colleges established under the Morrill act. In a majority of the states there is permissive legislation relative to the introduction of manual training, including drawing, in the elementary schools. In many states instruction in these branches is required in all towns having above a certain specified population. In twenty-four states legal provision has already been made for the encouragement or support of industrial education beyond the general provision for the manual training in elementary schools. The following gives an outline of the provisions in those states having such provisions:

Alabama—Provides for the establishment and maintenance of a branch agricultural experiment station in each congressional district. The annual appropriation for each school is $4500.

Arkansas—Has four state public schools of agriculture, appropriating annually $160,000 for their support.

California—Permits but does not provide for.

Connecticut—Aids in the support of two schools giving instruction in the principles and practise of trades. Total amount is $50,000 for both schools.

Georgia—Aids district agricultural high schools to the limit each of $2000.

Illinois—No special provision, local option.

Indiana—Authorizes industrial and manual training in cities of more than 100,000 and confers power to raise money by taxes.

Iowa—Has no law but aid is given for manual training.

Kansas—Authorizes local boards to levy tax of one half mill for the equipment of industrial training schools or departments. State aids such schools to the limit of $250 annually.

Kentucky—Does not provide but the cities do.

Maine—Provides for and aids to the extent of two-thirds the salaries of the instructors, subject to the approval of state superintendent. Has a commission which has made valuable recommendations.

Maryland—Gives state aid to county manual training schools or departments, limit $1500 each. Also aids high schools having commercial courses.

Massachusetts—Has a deputy commissioner of education whose duty it is to encourage and supervise forms of vocational education supported by the state. Grants permission to towns and cities to provide independent vocational schools and to provide evening and part time courses for persons already employed. Permits two or more cities to join for the purpose of maintaining vocational courses or schools; aids to the extent of one-half the net expense of such schools, provided the school has been approved by the state authorities.

Michigan—Authorizes and aids county schools of agriculture and domestic economy to extent of ⅔ of the cost if approved by state authorities.

Minnesota—Gives state aid to departments of agriculture, manual training and domestic science in state high, graded and consolidated schools if approved by state board. Maximum limit of $2500 to any school.

Nebraska—Does not provide but the cities do.

New Jersey—Contributes half the cost of maintainance and authorizes the locality to levy a tax for the remainder; maximum limit of aid is $10,000.

New York—Authorizes local board to establish such schools and gives aid to the extent of $500. Has a state director of trade schools.

North Dakota—Authorizes and aids such schools.

Ohio—Provides for manual training but the cities do most.

Oregon—Provides for courses in any high school under supervision of state board.

Pennsylvania—Requires that manual training courses shall be provided and aids by direct appropriation established vocational schools. Has three deputy state superintendents of education in charge of work.

Texas—Gives aid to the extent of half the cost of maintaining courses in agriculture, domestic economy and manual training subject to the approval of state board. Maximum limit $500. Aid is not permanent.

Utah—Permits vocational courses to be prescribed in existing schools.

Vermont—Aids schools with approved manual training courses to the extent of $250 per year.

Virginia—Provides by law and has ten schools in operation.

Wisconsin—Has a State Board of Industrial Education and a Commission to encourage Industrial Education; aids county schools having industrial courses which are approved by state.

Thus in the majority of cases heretofore the vocational training has been almost altogether in the form of agriculture or home-making and with manual training as an addition or incidental to existing courses in high and secondary schools. The problem therefore of true *industrial* education is comparatively new and has been met in only a few states such as Massachusetts, Maine, New York, Indiana and Wisconsin. In order to study the subject and learn the best methods of accomplishing the desired object we need therefore only consult the records of the results in Massachusetts, Maine, New York and Wisconsin.

An especially appointed commission in Maine has made a very careful study of the subject and placed the results of its conclusions in a valuable report. This report is dated 1910. The records do not show that the conclusions of this commission

have been carried out to the extent of perfecting an operating system.

While there are a great many institutions of vocational training in New York State it appears to be not as correlated as in Massachusetts and Wisconsin and the initiative appears to be in the cities and localities themselves. The state board is ready and prepared to give advice but does not have the control that is provided for in Massachusetts and Wisconsin.

In the opinion of this committee the feature of the Massachusetts and Wisconsin laws which causes them to excel those of all other states is the provision that in order for a vocational school to receive state aid it must receive the state's approval of many of its important features, such as courses, teachers, buildings, methods, time and accounts. This clause is used as an inducement to encourage the local boards to consult with the proper representative of the state board from the beginning of the organization of the school, rather than await the exact period when money is requested of the state. The state board includes an assistant superintendent who has made a special study of the subject of vocational training, and, as members of the board, are private citizens representing the points of view of employers and employees.

Thus to crystallize and collect the best ideas on the subject of legislation and provisions for vocational training it is only necessary to pick out the best points of the methods of Massachusetts and Wisconsin and combine them.

Outline of a Scheme for Industrial Education Based Largely on the Laws of Massachusetts and Wisconsin

Either a state board of industrial education containing representatives of both employers and employees and independent of the usual state board should be appointed, or an advisory board of similar character should work with the regular board of education.

The state superintendent or, in case the duties are sufficient to warrant it, an assistant for industrial education, should be appointed and should be authorized to approve, with the board, the courses of study and to certify that the work of the various schools is satisfactory. This superintendent should be authorized to attend industrial conventions and make investigations outside the state as well as within.

The board of education should have control over all state

aid given and aid should only be extended to those schools that have received the approval of the board and superintendent. The Board of Education should be authorized to investigate and aid in the introduction of vocational education and to initiate and superintend the establishment and maintenance of the schools. Three classes of independent schools should be recognized, such as industrial, agricultural and household arts, and each of these schools should have day instruction, part-time and evening classes. Attendance upon such day or part-time classes should be restricted to those between fourteen and twenty-five years of age and should be compulsory for those between fourteen and sixteen. Attendance at evening classes should be restricted to those over seventeen. The local board of education should be authorized to establish and maintain independent vocational schools and in the establishment of such schools should call in the advice of the state superintendent and after adopting a plan of organization and administration submit this plan for approval to the state board. It is desirable that local and district boards of trustees appoint an advisory committee composed of members representing local trades, industries and occupations. The state should reimburse the local district to the extent of one-half the net expenses of the school, providing the form of organization, control, location, equipment, courses of study, qualification of teachers, methods of instruction, conditions of admission, employment of pupils and expenditures of money are in accordance with the approved methods of the state board.

The community should provide the buildings and equipment and sufficient money for the operation of the schools and after a year's operation the state should reimburse the community the amount stipulated. In order that this amount may be easily determined uniform methods of accounting in the schools should be required.

Each locality should endeavor to make its courses meet its local needs and should, if possible, endeavor to arrange cooperation between the schools and the local industries so that the school shall prepare the students to be successful in those industries, and if possible so that the local industries supply the opportunity for practical work. To this end it is desirable that either on the local board or the local advisory board persons interested in the local industries be represented.

It is desirable that a reasonable tuition fee be charged in order

to discourage from attending those persons who have no serious purpose.

It is desirable that all children from fourteen to sixteen years of age be compelled to attend these classes at least one day per week or the equivalent thereof and that their working hours, if employed, should be such that this attendance would not be an unreasonable burden.

Provision should be made that illiterate minors over sixteen years of age should be required to attend the evening schools.

The training given should be designed to encourage the children of the locality to enter the local industries and to fit them to become leaders in those industries; thus the children would be kept at home, would be assured of useful and successful careers and the local industries would be kept in the hands of natives of the community.

Laws of Massachusetts on State Aided Vocational Schools

State Administration and Supervision

Section 2. The board of education is hereby authorized and directed to investigate and to aid in the introduction of industrial, agricultural and household arts education; to initiate and superintend the establishment and maintenance of schools for the aforesaid forms of education; and to supervise and approve such schools, as hereinafter provided. The board of education shall make a report annually to the general court, describing the condition and progress of industrial, agricultural and household arts education during the year, and making such recommendations as the board may deem advisable.

TYPES OF SCHOOLS

Section 3. In order that instruction in the principles and the practise of the arts may go on together, independent industrial, agricultural and household arts schools may offer instruction day, part-time and evening classes. Attendance upon such day or part-time classes shall be restricted to those over fourteen and under twenty-five years of age; and upon such evening classes to those over seventeen years of age.

LOCAL ADMINISTRATION AND CONTROL

Section 4. Any city or town may, through its school committee or through a board of trustees elected by the city or town to serve for a period of not more than five years and to be known as the local board of trustees for vocational education,

establish and maintain independent industrial, agricultural and household arts schools.

Section 5. 1. Districts composed of cities or towns, or of cities and towns, may, through a board of trustees to be known as the district board of trustees for vocational education, establish and maintain independent industrial, agricultural or household arts schools. Such district board of trustees may consist of the chairman and two other members of the school committee of each of such cities and towns, to be appointed for the purpose by each of the respective school committees thereof; or any such city or town may elect three residents thereof to serve as its representatives on such district board of trustees.

2. Such a district board of trustees for vocational education may adopt for a period of one year or more a plan of organization, administration and support for the said schools, and the plan, if approved by the board of education, shall constitute a binding contract between the cities or towns which are, through the action of their respective representatives on the district board of trustees, made parties thereto, and shall not be altered or annulled except by vote of two thirds of the board, and the consent of the state board of education to such alteration or annulment.

Section 6. Local and district boards of trustees for vocational education, administering approved industrial, agricultural or household arts schools, shall, under a scheme to be approved by the board of education, appoint an advisory committee composed of members representing local trades, industries and occupations. It shall be the duty of the advisory committee to counsel with and advise the local or district board of trustees and other school officials having the management and supervision of such schools.

REIMBURSEMENT

Section 8. Independent industrial, agricultural and household arts schools shall, so long as they are approved by the board of education as to organization, control, location, equipment, courses of study, qualifications of teachers, methods of instruction, conditions of admission, employment of pupils and expenditures of money, constitute approved local or district independent vocational schools. Cities and towns maintaining such approved local or district independent vocational schools shall receive reimbursement as provided in sections nine and ten of this act.

Section 9. 1. The commonwealth, in order to aid in the maintenance of approved local or district independent industrial and

household arts schools and of independent agricultural schools consisting of other than agricultural departments in high schools, shall, as provided in this act, pay annually from the treasury to cities and towns maintaining such schools an amount equal to one half the sum to be known as the net maintenance sum. Such net maintenance sum shall consist of the total sum raised by local taxation and expended for the maintenance of such a school, less the amount, for the same period, of tuition claims, paid or unpaid, and receipts from the work of pupils or the sale of products.

2. Cities and towns maintaining approved local or district independent agricultural schools consisting only of agricultural departments in high schools shall be reimbursed by the commonwealth, as provided in this act, only to the extent of two thirds of the salary paid to the instructors in such agricultural departments: provided, that the total amount of money expended by the commonwealth in the reimbursement of such cities and towns for the salaries of such instructors for any given year shall not exceed ten thousand dollars.

3. Cities and towns that have paid claims for tuition in approved local or district independent vocational schools shall be reimbursed by the commonwealth, as provided in this act, to the extent of one half the sums expended by such cities and towns in payment of such claims.

Section 10. On or before the first Wednesday of January of each year the board of education shall present to the general court a statement of the amount expended previous to the preceding first day of December by cities and towns in the maintenance of approved local or district independent vocational schools, or in payment of claims for tuition in such schools, for which such cities and towns should receive reimbursement, as provided in this act. On the basis of such a statement the general court may make an appropriation for the reimbursement of such cities and towns up to such first day of December.

III. DESCRIPTION OF A FEW TYPICAL INDUSTRIAL AND VOCATIONAL SCHOOLS

A. Certain Schools in New York City

Pratt Institute. This Brooklyn private school, founded by Charles M. Pratt in 1887 and now under the control of his six sons, is adequately endowed and gives day and evening instruction to over four thousand students. There are at present five

schools of instruction among which is the "School of Science and Technology" which offers thorough practical courses planned to meet the needs of four different classes of students.

"First. Day Industrial Courses in Mechanics, Electricity and Chemistry, for young men who cannot afford the time and expense required for four-year college or engineering courses, but who are nevertheless ambitious to fill positions above the grade of skilled mechanics in manufacturing and industrial plants.

"Second. Day Trade Courses in Machine Work, Carpentry and Building, and Tanning, for those who wish practical and theoretical instruction in these trades.

"Third. Evening Technical Courses for those employed during the day in mechanical, electrical and chemical industries and related occupations.

"Fourth. Evening Trade Courses for apprentices and journeymen.

"The courses offered are as follows:

Day Industrial Courses

Steam and Machine Design	A two-year course
Applied Electricity	A two-year course
Applied Chemistry	A two-year course
Applied Leather Chemistry	A one-year course

Day Trade Courses

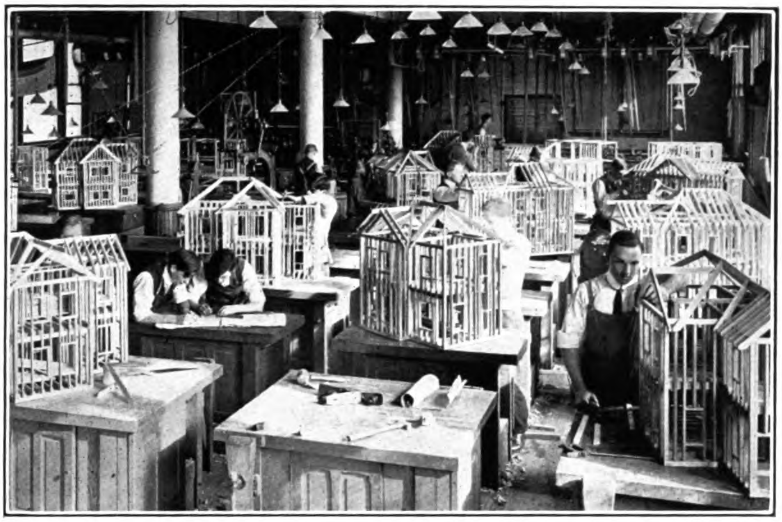
Machine Construction	A one-year course
Carpentry and Building	A one-year course
Tanning	A one-year course

Evening Technical Courses

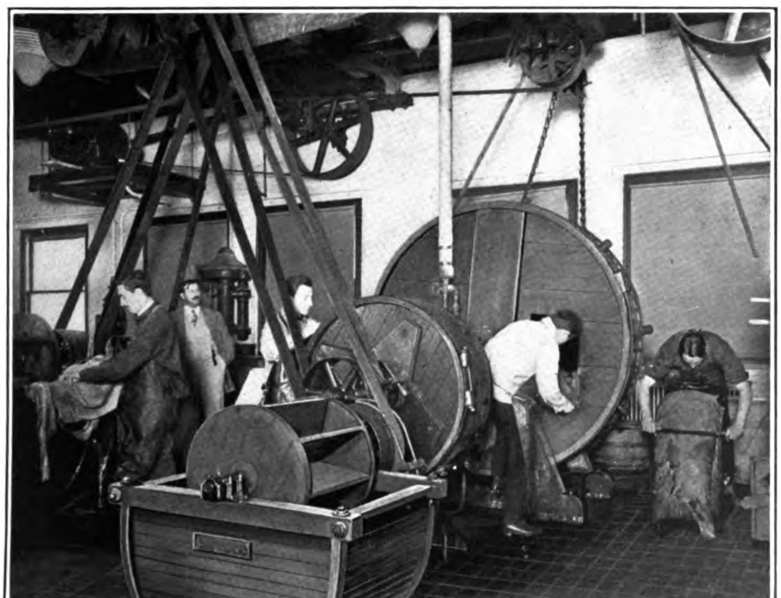
Technical Chemistry	Industrial Electricity
General Chemistry	Electricity and Mechanics
Qualitative Analysis	Electrical Machinery
Quantitative Analysis	Electrical Design
Organic Chemistry	
Mechanical Drawing and Machine Design	Practical Electricity
	Practical Mathematics
Mechanical Drawing	Steam and the Steam Engine
Machine Design	Strength of Materials
Mechanism	

Evening Trade Classes

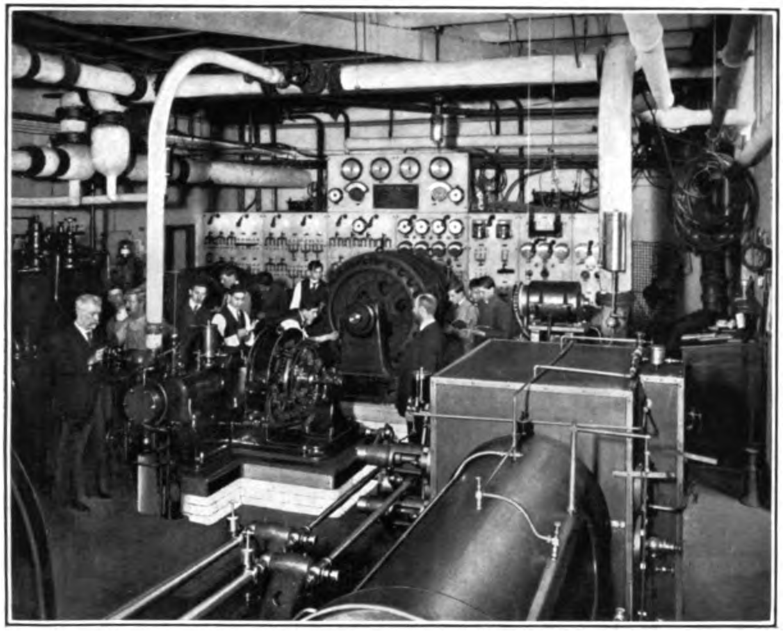
Machine-Work	Sheet-Metal Work
Tool-Making	Plumbing
Carpentry and Building	Advanced Wood-Working for Teachers"
Pattern-Making	



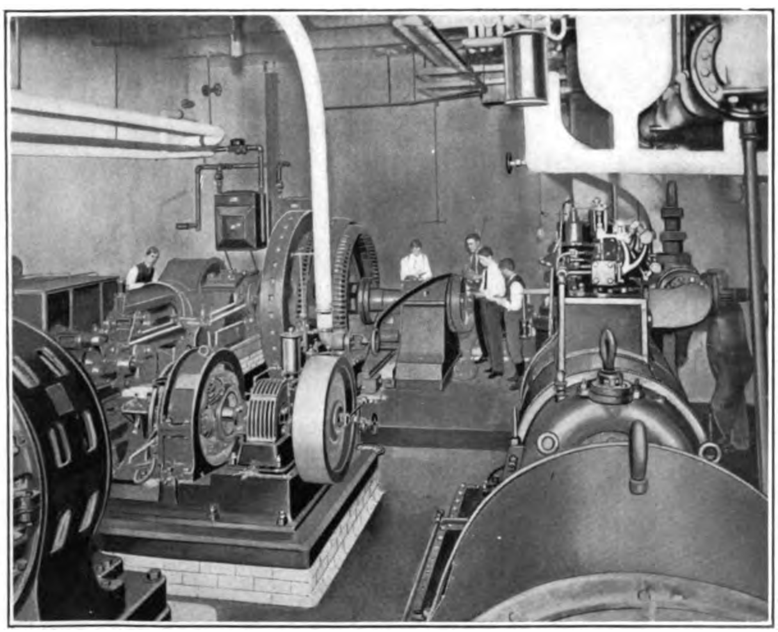
CLASS IN CARPENTRY AT PRATT INSTITUTE. [SHELDON]



TANNING LEATHER AT PRATT INSTITUTE. [SHELDON]



ENGINE ROOM AT STUYVESANT HIGH SCHOOL. [SHELDON]



ENGINE ROOM AT STUYVESANT HIGH SCHOOL. [SHELDON]

Requirements for admission to these courses are based upon the personality of the applicant rather than upon his prior scholastic achievements. A moderate honorarium is charged for each course.

The purpose of the school is to reach and help all classes of practical workers, both artists and artisans, and to give every student practical skill along some line of work. As a rule the instruction is intended to be more theoretical and less practical than that usually given in trade schools, whereas it is more practical and less theoretical than that usually given in engineering schools and colleges. This type of instruction is a unique feature of the Institute's work and its conception was inspired by the personal experiences of its founder, who was a self-made man of unusual breadth and power, and who started life as a machinist. In this connection there appear the following statements in a report by Samuel S. Edmands from the Department of Science and Technology:

"The trained workers in the electrical and mechanical fields, are, in a general way, divided into three different classes, the first and highest comprising the comparatively few men of superior ability and attainments who originate and direct operations requiring the services of many. In this class we find the engineering experts, designing and consulting engineers, and many others who bear the prime responsibility for the successful operation of industrial and engineering enterprises. The third and last class is composed of the skilled laborers and trained mechanics. Between the highest and lowest class there is a constantly widening field, the workers in which constitute the second class and occupy positions secondary and subordinate to the members of the first class, but nevertheless of great importance. They are the assistants to the engineers, the supervisors of skilled labor, or the specialists performing operations requiring a degree of knowledge and training in excess of that possessed by those in the third class. The commercial demand for technically trained workers of this second or intermediate grade is keen, and it is to afford a means for them to obtain the training that they need that the two-year technical courses in the Institute are primarily intended."

During 1910 the National Association of Tanners, desiring to affiliate with some educational institution in the formation of a tanning school, found that the Pratt Institute was prepared to train young men for its employ in the manner desired.

Experience in trade taught	Cabinet making	Pattern making	Carpentry and joinery	Plumbing	Blacksmithing	Machine shop practise	Steam engineering	Physics and elect. engineering	Advanced elect. engineering	Elect. wiring and installation	Chemistry	Freehand drawing	Mech. drawing	Architectural drawing	Total
None	15	37	53	11	53	6	21	144	9	36	43	57	117	81	683
Less than one year	2	5	6	6	0	3	15	0	6	15	6	16	12	17	109
one to two years	2	7	1	18	2	3	6	1	10	14	15	12	6	23	120
Two to three years	2	1	2	22	1	9	6	1	12	6	13	5	2	10	92
Over three years	3	1	0	45	0	16	4	3	9	4	10	6	0	2	103
Aim in taking trade course															
To improve knowledge of trade	7	14	9	91	1	31	21	11	28	40	40	31	50	52	426
To learn trade	9	28	50	5	8	3	21	47	15	30	31	55	87	78	467
To gain general information	8	9	3	6	47	3	10	91	8	5	16	10	0	3	214
Number of students admitted to different trade classes	24	51	62	102	56	37	52	149	46	75	87	96	137	133	1107
Average number of night students remain in each class after reg	58	48	36	45	34	71	33	44	71	65	60	46	51	57	50
Number of pupils who have obtained any industrial benefit as shown by advancement in position or wages	4	7	2	35*	14	2	0	2	6	21	6	12	4	21	136

*Increase of wages is governed principally by unions. All of present students declare they have been greatly benefited in theory and practise.

The formal report of the Tanning School Committee of this association contains an outline of the equipment and courses of instruction proposed by Pratt Institute. Its study is recommended to those interested in the formation of effective industrial curricula.

Public Schools. There are three public high schools in New York City which offer opportunities for instruction in vocational subjects, Stuyvesant, at 245 E. 15th St., Manhattan, for boys and men, Manual Training, on 7th Ave., Brooklyn, for boys and girls, and Bryant, on Wilbur Ave., Long Island City, for boys and girls. The courses of study, which are directed towards the technical industries, are similar to the ordinary high school courses, except that biology and history are omitted and manual training is given throughout four years.

Applied Mechanics, Steam, and Electricity forms a specialty course at Stuyvesant, is given to fourth year students, is open only to students of exceptional ability and is designed to prepare its graduates for giving efficient service immediately after graduation. The physical equipment of all these schools is adequate for the purpose and the laboratories are better equipped with apparatus than many engineering colleges, as will be evident after an inspection of the accompanying illustrations of the engine room at Stuyvesant.

The day instruction at this school is duplicated in the evening with some modifications, attending students being of the same general class as the day students but being from 8 to 10 years older. The evening instruction has for its motive increased earning capacity of the student. Besides preparing some evening students for entrance to college, others are fitted for positions in the trades. The effectiveness and characteristics of this work may be judged from the data contained in the foregoing table, which is based upon information supplied by the students and which refers to the academic year 1910—11.

B. A Few Schools Situated in the Middle and New England States

The Privately Endowed Industrial School. As an example of the recent development in privately endowed trade schools, Wentworth Institute, of Boston, Mass., may be considered as representative of the best ideas in its field. The Institute is designed to be a high grade trade school, that is, one which places a rational scientific foundation under the direct preparation for

mechanical trades and industry. The Director states that the aim is to develop artisans and skilled mechanics, and also to train men who wish to become inspectors, shop foremen, master mechanics and superintendents in industry.

As a school of this kind attracts young men of all kinds of preparation, the courses have to be adapted to various needs. There are, therefore, short one-year day courses for beginners and others with little practical experience, two-year day courses for those with some experience who wish to train themselves for positions of foremanship grade, and also evening courses where men employed in mechanical occupations during the day may either increase their skill and practical knowledge of their trade or study such supplementary subjects as will help them to advance to more responsible positions. While the school has been in operation but a few months, those in charge of it have had long experience in somewhat similar schools, so that the plans and methods of instruction may be considered in no way experimental. The following facts deal with the organization of the school and the results thus far accomplished will, therefore, be of interest.

Trades Taught. After a study of the probable demand for instruction the faculty of the Institute selected the following trades for the day courses. In the building trades,—carpentry, plumbing, and electric wiring; in the manufacturing trades,—machine work, foundry practise, and pattern-making; also, electrical construction for those who wish to become foremen in electrical industries, and machine construction for those who wish to become foremen in mechanical industries. While in the case of foundry practise, especially, great doubt was felt as to whether American boys could be made to see the possibilities, the possibilities of future development in the industry made this trade of importance. The class in foundry practise has proved one of the most successful of the day courses.

For boys employed during the day, evening classes were provided. For those who wish to perfect themselves in mechanical skill and practical knowledge of their trade, courses were offered in carpentry, pattern-making, machine work, tool-making, foundry practise, electric wiring, and plumbing; and for those who wish to supplement their knowledge and prepare themselves for more responsible positions, courses in practical mathematics, mechanical drawing, machine design, practical mechanics, strength and properties of materials, the steam engine

and the operation of power plants, applied electricity, and electrical machinery.

Selection of Students. Although the buildings and equipment of the Institute were hardly completed in September, 1911, more than three times as many applicants as could be accommodated appeared. In selecting from this large number, personal interview and oral questioning were the only practicable means. All academic standpoints of scholarship and skilled attainments were discarded and the attempt was made to measure the applicant's forcefulness, seriousness of purpose, and adaptability to the trade selected. In this way an earnest body of students was picked out.

Selection of Teachers. Of the 18 men who constitute the day school faculty, eight have charge of shop instruction. Six of the eight have special qualifications for this work, having occupied responsible industrial positions. The other teachers are school and college trained and they have had wide experience in industrial work. As the success of an institution like this depends largely on the teachers every effort has been made to get those properly equipped for this work.

Typical Curriculum. Following is a typical curriculum which shows clearly the scope of the work of this institution:

A typical curriculum for a one-year course is as follows:

	Hours per week		
	Fall term	Winter term	Spring term
Shop practise in machine-tool work, machine construction, bench work and tool-making, principles and practise of forging, tempering steel, foundry practise and pattern-making....................	20	20	20
Mechanical drafting and blue print reading..............................	6	6	6
Practical mechanics, materials of construction, and power transmission, etc., (recitations and laboratory practise)......	9	9	9
Practical mathematics, machine shop computations.........................	5	5	5

A typical curriculum for two-year courses is as follows:

FIRST YEAR

	Hours per week		
	Fall term	Winter term	Spring term
Practical Mechanics:			
Recitations	5	5	5
Laboratory practise	8	8	
Electrical Motors and Appliances:			
Principles of construction and operation, recitations			5
Laboratory			8
Mechanical Drafting:			
Shop drawing and machine details	8	8	8
Practical Mathematics:			
Shop computations and use of formulas	5	5	5
Shop Practise:			
Moulding and foundry work	8	4	
Pattern making		4	8
Forging and tempering	6		
Machine tool work		6	6

SECOND YEAR

	Hours per week		
	Fall term	Winter term	Spring term
Applied Mechanics:			
Mechanism of machinery, materials of construction, transmission of power, plant care and operation, etc.			
Recitations	5	5	5
Laboratory	8	8	8
Machine Sketching:			
Tool and jig design	6	6	6
Advanced Practical Mathematics, including useful applications of algebra, geometry and trigonometry	5	5	5
Advanced Shop Practise:			
Machine construction	10	4	4
Tool making		6	6
Optional			
Advanced jig and tool making	6	6	6
or			
Advanced machine construction	6	6	6

NOTE: In the two-year courses a considerable portion of the laboratory work is actual construction and for that reason the time spent in shop practise is somewhat reduced.

Vocational Instruction under the Direction of the New York State Department of Education. In 1908 a law was passed by the legislature of New York State providing for vocational and trade instruction in public schools. To put this law into effect the New York State Education Department organized a separate division of trade schools under the supervision of a chief. This division endeavors to keep in touch with the various labor organizations and with the manufacturers with a view to the promotion of education of such a nature that the young people of the state will be fitted to take up employment in the industries with the greatest possible efficiency.

The Department of Education recognizes two divisions of this field: (1) There are young people from 12 to 16 who need industrial education of a preliminary character. At this age young people are of little value in the industries, but they are of an age suitable for the acquirement of the fundamental principles of industry. Assuming that the ordinary school subjects of reading, spelling, writing, arithmetic, etc., have been fairly well mastered, it is assumed that the applications of these fundamental studies to shop work, shop accounts, business subjects, etc., may be profitably emphasized. It is not the aim in this part of the work to teach trades, but by means of manual training, drawing and other practical studies, the elements of all trades are taught.

Under the law of 1908 a number of vocational high schools have been organized, including a school at Albany near the headquarters of the State Department of Education. The Albany school is considered typical, and will be treated in more detail later.

2. The second division of industrial training recognized by the Board of Education is instruction in the trades. New York State contains a large number of groups of industrial workers engaged in printing, textile industries, shoe manufacture, ready-made clothing manufacture, manufacture of electrical apparatus, iron working, paper manufacture, etc. These groups need recruits especially prepared for their specialties. In addition to the general preparation given by the vocational high school, which is supposed to prepare the way for all trades and business activities, there are many special subjects which should be studied in order to make intelligent workers in, say, the printing business, shoe manufacture or electrical machinery manufacture. Schools for this purpose have been started by benevolent individuals and in some cases by the industries themselves.

However, the opinion seems to be general that, as public school education is intended to provide equipment for good citizenship, it is the duty of the state to furnish vocational training. It will take time to develop this side of the work of the Department of Education, which in the meantime must be provided by schools like the Mechanics Institute of Rochester, the Mechanics Institute of New York, The Stuyvesant Evening Trade School of New York, and others.

The State Department of Education has made a real beginning in the first division of its field mentioned above. State aid is given to schools which qualify under the law. In the 8th annual report of the Department, Mr. A. D. Dean, Chief of the Division of Vocational Schools, states as follows:

" *The Intermediate Industrial School.* The plan as now operating provides that five-twelfths of the school program shall be given over to the shop, laboratory and drawing instruction and that the remaining seven-twelfths be devoted to " book studies," which practically amounts to saying that the pupils shall for the remainder of the time take the regular elementary school studies corresponding to the seventh and eighth grades. These studies are related to the industrial studies as far as is possible. Both boys and girls have similar work in English and history. The arithmetic course for boys differs from that for girls. The geography is viewed as an outgrowth of the life-long problem of providing food, clothing and shelter. The physiology is studied from the view-point of hygiene and sanitation rather than the structural only. The shop, laboratory and drawing work differs with the sex considered.

Vocational Courses in the High School. The Education Department proposes a plan by which an average high school now teaching college preparatory, commercial, industrial and home-making subjects can economically and effectively develop courses of instruction along the lines suggested by the syllabus which shall have a well-blended liberal and vocational training. Instead of these schools offering commercial, industrial, and home-making subjects it is proposed that they offer well-defined courses for pupils who seek different destinations. A certain amount of the work will be common to all these courses and will consist of the prescribed studies which are deemed essential to a sound and symmetrical education and which, under normal conditions, should be prescribed for all pupils in a secondary school. These prescribed studies are English for four years, English

history with civics, algebra, plane geometry, biology, and physics. Another division consists of such elective subjects as may be necessary for pupils seeking different destinations.

The " industrial and agricultural purpose " courses have intensive courses in the agricultural and manual arts and drawing. The " home-making purpose " course is rounded out with strong courses in domestic science and art, household decoration, sanitation, and personal hygiene. It cannot be emphasized too often that a vocational course does not consist merely of vocational subjects thrown at random into a high school system. The vocational purpose must be satisfied by a definite course.

The law states clearly certain conditions which a vocational school must meet in order to be considered as entitled to special State aid. (1) It must be independently organized— not necessarily a separate building but most assuredly established with a distinct vocational purpose in mind; (2) it must have an enrolment of at least 25; (3) it must employ the full time of a teacher and (4) it must have a course of study meeting the approval of the Commissioner of Education. The first three conditions admit of no changes and are to be enforced in all places without variation from the word of the law. The fourth condition allows for considerable latitude and discretion. The course of study is not defined by the law; it may vary in different localities and connect with the different local industries, which vary in different parts of a great State. The course of study in agriculture and related subjects may emphasize dairying in St. Lawrence county, and fruit growing in Ontario county. An industrial course may concern itself with the shoe industry of Rochester or the knitting mills of Utica; it may omit mechanical drawing in Gloversville and emphasize it in Schenectady. The vocational training may be of rather the general industrial nature in Albany or have its specific trade aspects in Lackawanna. The only points that need to be considered in the establishment of such a school course in a high school system are: (1) Is it established to meet the vocational purposes in education? (2) Does it meet the requirements of the law?

The New York Department has ruled that five-twelfths of the weekly program of a vocational school department must be given over to the vocational studies chosen for the elective group. This particular ratio was settled upon after considering two propositions. (1) The present requirements for an academic diploma call for 41 counts in certain studies, primarily liberal.

These counts closely approximate seven-twelfths of the total number, 72, required for a diploma. (2) Vocational training of high-school grade demands a certain amount of liberal training. Preparation for a vocation should have academic recognition through a diploma if the work is of high school grade. The placing of the ratio five-twelfths vocational to seven-twelfths liberal will satisfy the time elements of both divisions of the course of study. Consequently the pupils in the vocational school course have the same liberalizing studies, or their equivalent, as do pupils in other courses. They take the same department examinations in English, history, algebra, geometry and biology when they follow the same syllabus as other pupils. When the school offers, as it should, special and practical courses in mathematics and science beyond, or in place of, those just mentioned, the work is inspected and if the definite outlines submitted to the Department are satisfactory, if the teacher is trained for his work, and if it is seen that he can make direct and useful applications of the abstract to the concrete shop, laboratory, or field work of the home and the school, then the Departments grant credits without examination. No examinations are given in the vocational subjects proper.

There are now 35 industrial and trade schools, employing 145 teachers. These schools have a day enrolment of 3370 pupils and an evening enrolment of 2933 pupils, or a total enrolment of 6303 pupils. There are 527 other pupils using the equipment, but not enrolled in these schools.

The Albany Vocational School was organized soon after the law of 1908 went into effect. It started with one hundred pupils selected from a large number of applicants prepared in the lower schools. The equipment of the school does not differ materially from that of manual training high schools, but very much greater prominence is given to the manual part of the course. This equipment comprises a wood shop with the necessary benches, bench tools, saw bench, band saw, speed lathes and accessories all electrically driven. A home-making department uses cooking tables, gas stoves and other necessities of the home, for instruction in domestic arts.

Book-work is not neglected, but it has a practical aspect. For example, in the study of algebra the formulas are stated in terms of the workshop and complicated equations are solved graphically. The formulas studied deal with such applications as electricity, mechanics and engine practise. In mensuration,

areas are studied by reducing plane figures to equivalent triangles, by counting squares when figures are drawn on squared paper by weighing similarly shaped areas cut from cardboard, sheet lead or iron. In scientific subjects like physics everyday applications are studied. Among these may be mentioned the radiation from water supply pipes, practical use of exhaust steam, steam boilers, and heating and ventilating.

Industrial work in this school is not confined to boys, but the needs of girls are carefully considered. The work for girls comprises housekeeping, sewing and design. The fundamental scientific principles underlying the household arts are taken up. Girls are taught to use their hands as well as their heads.

While the Albany school has been in operation but a short time, it has apparently demonstrated the soundness of the principles upon which it is founded.

Data Concerning Railroad Corporation Schools.

New York Central Lines Apprentice School System. As the New York Central plan has been worked out in great detail and as it comprises most of the features found satisfactory in other systems it may be considered as typical of the best practise in its line. Six years ago the New York Central lines put into operation at the larger shops a school system for the benefit of shop apprentices, in various trades. The purposes of these schools are:

1. To improve the quality of mechanical skill available in shop work.
2. To make apprenticeship attractive to intelligent boys.
3. To make it possible for the right kind of boys to rise from the ranks to positions as foremen and master mechanics.

School work is done in regular shop time under pay, and in the morning when the boys are at their best. The work is done under drawing and shop instructors appointed from the local shops, these instructors being under the direction of the officers of the company in charge of the local shop operations. The whole work is under the supervision of a superintendent of apprentices who in turn reports directly to the general superintendent of motive power.

The boys who apply for apprenticeships in the shops of the company are of various grades of education, some having practically no schooling, while others are high school graduates. The instruction is therefore somewhat varied in character, but is

mainly of two general types: drawing and numerical calculations and shop work. The drawing instruction is given in the rooms or small buildings especially devoted to this work. These rooms are fitted up in a simple style with drafting tables, blackboards, cabinets for storing boards and supplies, models, etc. The courses, which are laid out for all shops by the superintendent of apprentices, are of a nature to appeal to apprentice boys. Early experience with the work showed that school methods and especially college methods are not applicable to this class of instruction. Academic, numerical, geometrical and graphical problems make no appeal to the shop apprentice. He must be instructed in terms of his environment. Hence the objects which he is expected to draw are the familiar things with which he works in the shops. Small locomotive parts, parts of shop tools, wrenches, nuts, etc., form the drawing exercises. Very simple subjects are assigned at the start, leading up to rather complicated ones toward the close of the four year course. The work includes tracing so that the student finally leaves his work as if for use in actual construction. In many cases the apprentices actually prepare drawings for foremen, supplementing the work of the regular draftsmen.

The drafting room periods afford an opportunity also for testing the ability of the students to think for themselves. A large number of problems are assigned for home work, these problems being all of a simple and practical character. Solutions to the problems are handed in from time to time, and by means of blackboard exercises the real ability of the pupils in solving problems is tested.

Most of the time of the apprentices is put in at actual shop work under the direction of the shop instructor. This instructor is a practical mechanic who is familiar with all branches of shop work. His duty is to see that the pupil is taught thoroughly all branches of the selected trade. The instructor shifts the pupil from one line of work to another, giving him sufficient time to permit a thorough mastery of each part. For example, if a boy elects to learn the trade of machinist, which requires four years, his time will be divided up roughly as follows: helping in shop, 0-3 months; bench work, 6-12 months; light tool work, 3-6 months; heavy tool work, 3-12 months; in air brake department, tool room or brass tool, 3-6 months; in erecting shop, 16-24 months. The instructor shows the apprentice how to perform each operation assigned to him and sees that the work is done

thoroughly. He thus relieves the foreman of the necessity of instructing apprentices and, as he is a specialist in this line, the work is much better done than formerly. It is understood that while the shop course is going on the apprentice is also working in the drafting room as explained earlier.

The instruction of apprentices is quite different from school work of any kind, as will be evident from the description given. The primary function of the course is to teach the apprentice to " do things." Mental development is, of course aimed at, but this mental development comes as a result of the continual exercise of the constructive faculty. Practically no text-books can be used in such a course, as the needs of the pupils are so varied. Lectures, examinations and recitations, as used in school, have little place.

The results of the system have been highly gratifying to the company, and although the experiment has been in operation but a short time the benefits have been evident in an increase in shop output, a reduction in the amount of spoiled work, and increased desire on the part of the boys to prepare themselves for trades (including even some trades which a few years ago did not attract boys at all) and a general improvement of the spirit in the shops. The shop instructors meet from time to time to discuss their problems and, as they work through a central organization, their efforts are marked by unity of plan and purpose.

The Pennsylvania Railroad Apprentice School. An instance of a continuation school, doing a large amount of good in its community, is the one maintained by the Pennsylvania Railroad Company in Altoona, Pa., which was inaugurated under the direction of engineers of the company and the Chairman of the Committee. In this school something over 250 apprentices spend one-half a day a week in a specially prepared building, which in itself with its equipments was comparatively inexpensive. Three instructors are required. The curriculum consists largely of practical drawing, English, natural science and mathematics.

The English is taught in a manner best adapted, in the opinion of the instructors, to improve the pupils' ability to readily understand shop or similar reports and to make verbal or written reports in clear language. The natural science studies take up elementary functions having to do with features of combustion in the firing of boilers, the simple principles underlying machine mechanisms, the qualities and characteristics of mate-

rials used in machine construction, and similar practical information which should add to the intelligent performance of the workman's duties. The mathematics taught is a study of the fundamental principles of arithmetic, algebra, geometry, etc., as they apply to the ordinary simple mental or written computations which are demanded of the skilled mechanic in the course of his labor. The drawing is of a practical sort, such as to give the mechanic keener appreciation of working drawings required in construction, and to enable the management to select men of suitable caliber for their draughting rooms when needed. The instruction in English and natural science, of the nature indicated, seemed at the outset of the work to be desirable, and the experience thus far obtained indicates its material value in improving the quickness and intelligence of the young men pursuing the work.

The apprentices are under the supervision of the foremen who in turn are in close touch with the school instructors. The use of the foreman, instead of the special shop instructors employed in some other corporation schools, has much to commend it. The foreman of sufficient intelligence to carry on the industrial operations of his department should have, if he is the proper man for his place, ability to direct the apprentices to proper advantage. Further, adding this special supervision and instructional function to the responsibilities of the foreman seems rather to add to his effectiveness and interest in his work than otherwise. And still further, by using the foreman the schools are tied up more closely and correlated to the better advantage with the industrial organization as a whole than is otherwise possible.

The school instructors and foremen are required to submit exhaustive weekly, monthly, semiannual, and annual reports to the organization management. These reports have apparently proved of value in enabling the management to weed out apprentices who are unworthy and to place into line of promotion young men who are of noteworthy merit. This latter function is in itself of sufficient worth to warrant the expense of the school.

The success of the school, though in operation but slightly over two years, has been marked and the pupils themselves have been enthusiastic over this work. Those completing the course have, in many cases, petitioned to be allowed to continue further. That the management believes the expense of the school to be warranted by the results, is indicated by the fact

that it seriously contemplates the extension of the system to other divisions of the railroad.

Tabulation of Data Concerning Instruction by Cer ain Steam Railroads. A number of important railroads have well organized systems of instruction of apprentices. Mr. W. H. L. Hale of the Pennsylvania State College and Head Instructor in the Pennsylvania Railroad Apprentice School, just referred to, recently made a careful study of the instructional work of a number of systems . His findings are summarized in the following tables:

1. EXTENT OF INDUSTRIAL EDUCATIONAL WORK.

Name of road	Where applied	How applied	No. of points where instruction is provided	Headquarters for the Educational Department
Atchison, Topeka & Santa Fe Ry.	To apprentices in the Mechanical Dep't. over the entire system.	Through an organized apprenticeship system extending over entire railway and providing both shop and school, instruction.	29 (2–31–11)	Topeka, Kansas.
Canadian Pacific Railway.	To apprentices in the Mechanical Dep't. at the Montreal, Toronto and Winnipeg shops.	Through apprenticeship operated independently at the several shops and providing both school and shop instruction.	3	No central organization for the apprentice work of the system. Each shop operated independently as regards apprentice training.
Delaware & Hudson Company.	To apprentices in the Mechanical Dep't. over entire system.	Through an organized apprenticeship system providing both shop and school instruction.	3	Green Island (Albany, N. Y.).
Erie Railroad.	To apprentices in the Mechanical Dep't.	Through an organized apprenticeship system providing both shop and school instruction.	5	Meadville, Penn.
Grand Trunk Ry.	To apprentices in the Mechanical Dep't.	Through an organized apprentice system providing compulsory evening school instruction and a system of examination for promotion in the shops.	7	Montreal, Quebec.
N. Y. Central Lines.	Same as above.	Through an organized apprentice system providing both shop and school instruction.	12	Grand Central Terminal, New York City.
Union Pacific R. R. Company.	Open to all employees of the railroad. Evening apprentice school at Omaha, Neb.	Through correspondence courses conducted by an Educational Bureau of Information. Apprentice evening school at Omaha.	Reaches all employees who voluntarily apply for instruction.	Omaha, Nebraska.

2. ORGANIZATION EMPLOYED.

Name of Road	Higher Officer in Charge	Officer in Direct Charge	Assistant Officer in Direct Charge	Officer in Charge at Local Shops	Instructors at the Local Shops
Atchinson, Topeka & Santa Fe.	General Supt. Motive Power.	Supervisor of Apprentices.	School Instructor at Topeka, Kansas.	Master Mechanic or Superintendent of Shops.	School and Shop.
Canadian Pacific Ry.	Superintendent Motive Power.	Senior School Instructor.	———	Local Shop Head.	School and Shop.
Delaware & Hudson Company.	Superintendent Motive Power at Albany.	General Efficiency Engineer.	Traveling School Instructor.	Local Shop Head.	School and Shop.
Erie R. R. Company.	General Mechanical Superintendent.	Shop Specialist or Supervisor.	Assistant Supervisor.	Local Shop Head.	School and Shop.
Grand Trunk Railway System.	Superintendent Motive Power.	Chief Draughtsman at Montreal.	———	Local Shop Head	School
New York Central Lines.	General Superintendent Motive Power.	Superintendent of Apprentices.	Asst. Supt. of Apprentices.	Master Mechanic or Local Shop Head.	School and Shop.
Union Pacific R. R. Company.	Vice-President.	Chief of Educational Bureau.	Asst. Chief of Educational Bureau.	———	Apprentice evening school instructor at Omaha only.

4. NUMBER OF INSTRUCTORS AND PUPILS

Name of road	No. of points reached	Total No. of apprs. instructed on system	Total No. of instructors
A. T. & Santa Fe Railway.........	29	645	40
Canadian Pacific Ry..............	3	353 of whom 223 are at Montreal.	School 5 Shop 6
D. & H. Co.....................	3	95	School 2 Shop
Erie R. R. Co.....................	5	253	School 3 Shop 3 (?)
Grand Trunk Ry. System..........	7	329	——
N. Y. Central Lines...............	12	690	School 12 Shop 12
Union Pacific.....................	2700 from all branches of service. Approx. 175 Apprentices included on entire system not all taking course		——

A paper presented at the 29th Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June 28, 1912.

(Subject to final revision for the Transactions)

APPLICATION OF ELECTRIC DRIVE TO PAPER CALENDERS

BY E. C. MORSE

Motors have been used in paper mills for the last twenty years and have been applied with success to every machine used in the process of making paper.

By means of motors it has been possible to study the power requirements of various machines and much useful information has been obtained for the manufacturer of the paper, of the machine, and of the motor.

As far as the writer knows, very little of this information has been published and it is the intention of this paper to set forth facts that have been observed and state the possible laws that may be deduced from these facts.

This paper is confined to the finishing department of the paper mill and more particularly to the motor drives for three types of paper calenders.

Paper as it leaves the machine does not, for many purposes, have a sufficiently high glaze and it is therefore necessary for it to undergo some further process known as calendering. This may be done in one of three ways: first, the whole roll may be calendered by passing the paper through a "super or webb calender;" second, the paper may be cut in sheets and these sheets calendered in a "sheet calender;" third, the paper may be cut in sheets and calendered in a "plater." The method used depends on the kind of paper and the kind of finish desired. All "loft" or air-dried papers are finished either in a sheet calender or a plater, as the paper must be cut into sheets before drying. These papers are usually of the higher grades.

Super Calenders

A super calender (Fig. 1) consists of a stack of rolls carried in upright housings, each roll having its own bearings which are so constructed that they are free to move vertically. Power is usually applied to the bottom roll (occasionally to the third) and the other rolls are driven by friction from this one. Oil for lubrication is supplied to the top journals and is carried down through the other bearings by gravity. The top and bottom roll and the small or intermediate rolls are nearly always steel; the other rolls may be either steel, chilled iron, paper or cotton, depending on the kind of paper and finish desired. A system of levers with weights is used to apply pressure to the top roll in order that there will be proper pressure on the paper. The number of rolls is nearly always odd and may be three, five, seven, or nine, usually seven or nine. The diameter of the bottom roll varies from 18 in. to 24 in., the intermediate from 10 in. to 16 in., the cotton or paper rolls from 14 in. to 20 in. Calenders are built varying in width from 36 in. to 125 in.

Requirements for Drive of a Super Calender. One end of the paper is taken over the top of the calender and then passed back and forth between the rolls, shown in Fig. 1, to the bottom of the stack and then to the winding roll. In order to pass this paper through between the rolls, which process is known as "threading in," it is necessary to operate the rolls at a slow speed and it is very important that this speed be constant. This speed varies in different mills from 20 ft. per minute to a maximum of 100 ft. per minute. As soon as the paper is "threaded in" and started on the winding roll, the calender must be speeded up and will then operate at a speed between 400 ft. to 800 ft. per minute, depending on the method of drive, the operator, and the kind of paper calendered. It is therefore necessary to provide at least two speeds on each stack, one a slow speed and the other a high speed, regardless of the method of supplying power. It is very important that the acceleration be smooth from the slow speed to the high speed in order not to break the paper and cause the consequent loss of production. It is also very advisable to have a method of slowing down, when a weak or torn place in the paper appears, and of smoothly accelerating to highest speed again. It is convenient to be able to stop the calender from other places than at the operator's usual stand, in case of emergency.

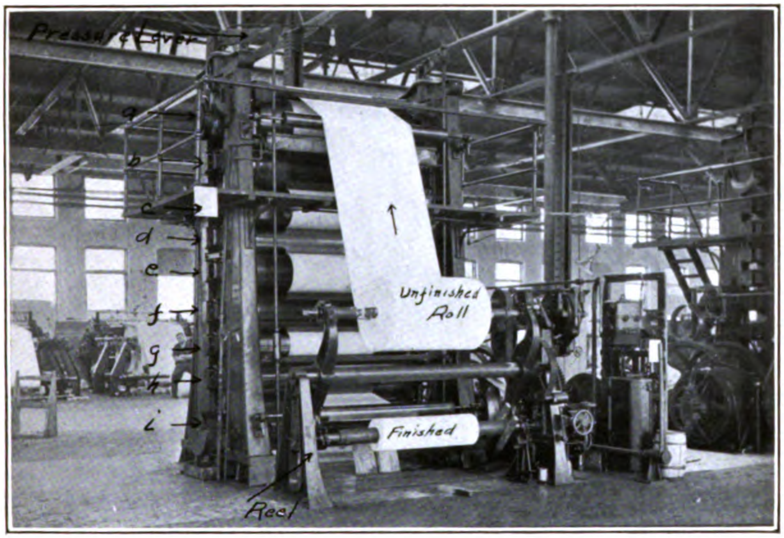


FIG. 1.—WEBB CALENDER. [MORSE]

a —top roll, steel.
i — bottom roll, steel.
b, *c*, *e*, *f*, *h*— fabric rolls.
d, *g*—intermediate rolls, steel.

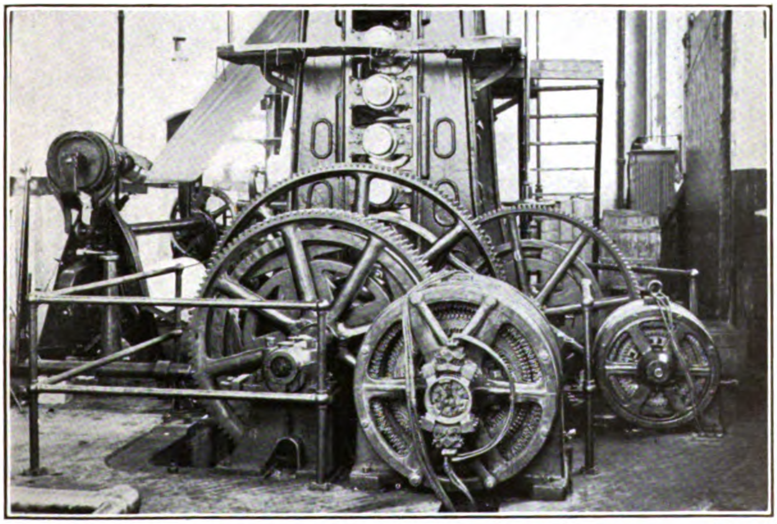


FIG. 3.—WEBB CALENDER—TWO-MOTOR DRIVE. [MORSE]

Method of Drive

Group or Shaft Drive. Calenders were originally driven from a line shaft and still are in many mills. This shaft may or may not be driven by a motor. Fig. 2 shows the method of drive and how the "threading in" speed is obtained. The cycle of operation is as follows:

Throw in horn clutch *a* which starts rolls at their slow speed. After paper is threaded in throw in friction clutch *b* which connects high-speed driving pulley and increases roll speed to maximum. As the speed increases clutch *a* is automatically thrown out. To stop the calender throw out friction clutch *b*. Both pulleys are running all the time. Clutch *a* is now nearly always made a friction clutch and a horn clutch put on pulley *c*, both being operated from the same lever. With this arrangement

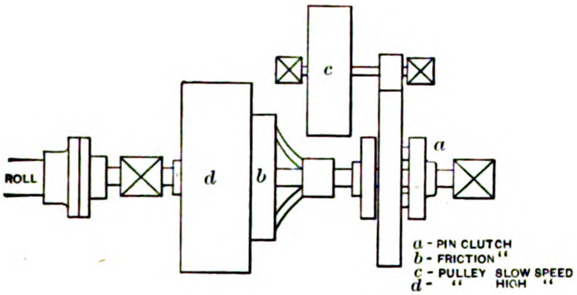


Fig. 2.—Webb Calender—Mechanism for Group or Belt Drive.

the horn clutch is thrown in first and then the friction clutch which is now at *a*. This reduces the shock and allows the calender to be stopped if need be while "threading in."

The high speed must be a compromise between the maximum that any of the paper will stand, and a slower speed, which is best for the weakest paper.

Engine Drive. Abroad, and in one or two cases in this country, individual variable speed engines are used to drive calenders. As no steam is required ordinarily around a calender this engine drive means long live and exhaust steam lines. This drive requires space in the basement and an engineer in attendance. A belt drive through floor is used, with the attendant grease and dirt which is always present around a reciprocating engine. A two-cylinder engine must be used and even then a

uniform torque is not obtained. This type of drive does not meet with favor among American manufacturers.

Two-Motor Drive. The most natural step, when motors were applied to calenders, was to belt motors to the old mechanism which was used when the calender was belted to the line shaft. It was at once seen that a simpler, more compact arrangement could be made, as well as the belts eliminated, if the motors were mounted on same base with the clutches and gears, and geared to the driving mechanism. (See Fig. 3). This arrangement is shown diagramatically in Fig. 4 and the cycle of operation is as follows:

Close the circuit breaker, then start small motor, now throw

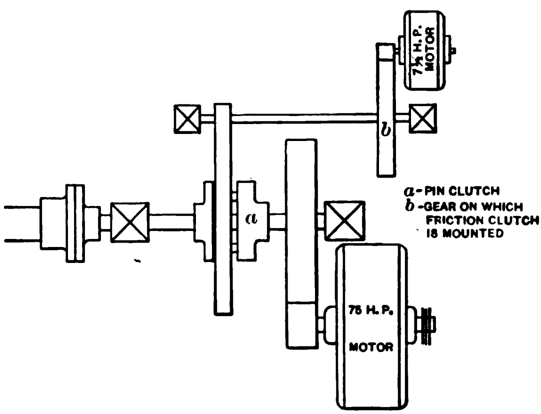


FIG. 4.—WEBB CALENDER—MECHANISM FOR TWO-MOTOR DRIVE.

in horn clutch at *a*, which will start the calender at the slow speed. After paper is threaded in, advance controller on large motor, which increases speed of calender and automatically throws out horn clutch at *a*. The small motor may be shut down or left running, as desired. To stop calender the power is thrown off.

It is usual practise now to mount a friction clutch also at *b* which is controlled from same lever as *a* and operated as described under "Group Drive."

It is now a simple matter to make the large motor an adjustable speed motor and obtain smooth acceleration from slow to high speed. This type of motor makes it possible to gear the calender so that the maximum speed will be the maximum at which it

is possible to finish any of the paper and the calender can easily be slowed down to accommodate weaker paper or for a different finish.

Two Motors Replaced by One. It is possible to do away with the small motor used in a two-motor drive and by means of gearing and clutches to operate the calender at the "threading in" speed from the large motor. This is shown in Fig. 5. The cycle of operation is as follows.

Close the circuit breaker and start up motor. The large gear *d* and pinion *e* are mounted on a bushing loose on the shaft. In starting horn clutch *a* is first thrown in, the friction clutch *c* being open. As gear *d* is loose on shaft the calender is driven at the slow speed through back gears. After the paper is

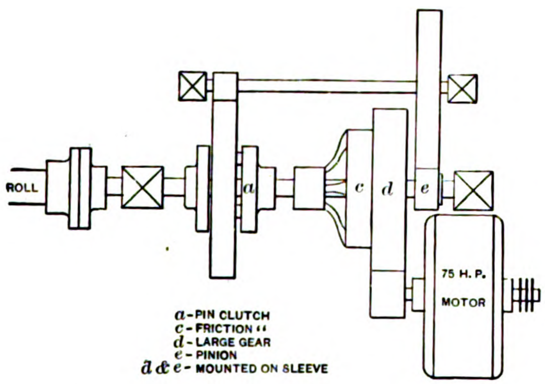


FIG. 5.—WEBB CALENDER—MECHANISM FOR ONE-MOTOR DRIVE.

"threaded in" friction clutch *c* is thrown in, connecting gear *d* to shaft and calender speeds up to maximum while horn clutch *a* is thrown out automatically.

From the operator's standpoint this drive is practically as good as the "Two-Motor Drive" previously described. The electrical features will be discussed later.

One Motor Direct Geared. In this method of drive there is only one large motor direct geared or belted to the driving roll as shown in the diagram, Fig. 6. It is therefore necessary to obtain the "threading in" speed or a speed $\frac{1}{8}$ to 1/13 of the maximum by reducing the speed of the motor by inserting resistance. The cycle of operation is as follows:

Close the circuit breaker and adjust the controller until the

motor operates at the desired speed. All speed changes are made by the movement of the controller handle.

This drive eliminates all clutches, nearly all the gears and makes mechanically a very compact and simple drive. The "threading in" speed, necessarily, is very unstable, as will be seen when the electrical features are taken up.

Power Requirements

General Characteristics. The power consumed by a calender is entirely used in overcoming friction, therefore, a calender requires (within limits) a constant torque. It has further been found, from tests, that with most grades of paper, only 15 to 20 per cent of the power consumed is required by the paper itself, and 80 to 85 per cent of the power is consumed in overcoming the friction of the machine. Therefore, to drive a given calender at

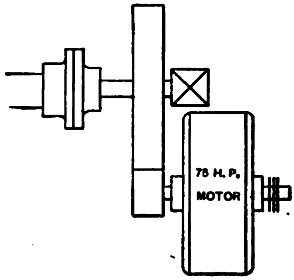


Fig. 6.—Webb Calender—One-Motor Drive, Direct Geared.

various speeds, a motor or engine is required that will give constant torque rather than constant horse power over the range of speed desired.

Slow Speed Power Requirements. As previously stated, means must be provided to obtain a slow or "threading in" speed, approximately $\frac{1}{8}$ to 1/13 the maximum speed of the calender, in order that the feeding in of the paper may be done as easily and quickly as possible. This speed should remain practically constant with the change in torque from the calender alone without weights, to the calender with paper completely "threaded in with weights." This increase in torque varies from 10 to 75 per cent, depending on the kind of paper or cardboard being calendered. Many slow speed drives have been tested and the maximum power required by the motor at 50 to 60 ft. per min. on the paper has never exceeded five to six horse power, regardless of the size of the calen-

der, kind of paper, and the type of drive. Fig. 7 shows the results of various tests on different paper calenders at "threading in" speeds. The points all fall close to a straight line, showing the condition of constant torque. These values represent the power consumed by calender and drive with paper completely "threaded in". A motor smaller than $7\frac{1}{2}$ h.p. is not to be recommended if a separate motor is used, and the gearing can be made easily to accommodate a motor speed of 850 revolutions.

High Speed Power Requirements. When we come to determine the power required by a calender when calendering paper, there are many points to be considered. These are listed in order of their relative importance, and then each taken up in detail:

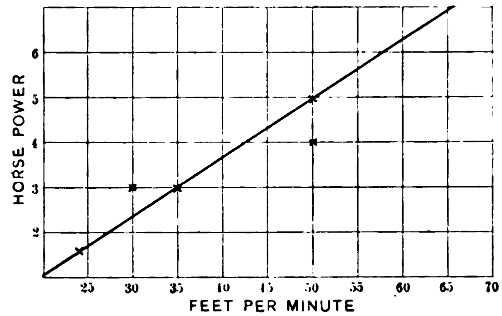


FIG. 7.—POWER REQUIRED FOR THREADING IN.

a. Material, size, number and condition of rolls: steel; chilled iron; paper; cotton.

b. Number of "nips" or passes of paper.

c. Type bearings: plain journals; roller bearings.

d. Kind of stock: paper; cardboard.

e. Pressure on rolls.
   (1) Power varies with kind of rolls.

f. Width of stack or rolls.
   (1) Active width is width of paper calendered.

g. Surface speed of rolls in feet per minute.
   (1) Difference in speed between rolls and paper.

a. The varying of the power with the kind of rolls is closely interlinked with the varying of power due to different pressures applied. This subject as far as the writer knows has never been investigated carefully. It is known that the power varies accord-

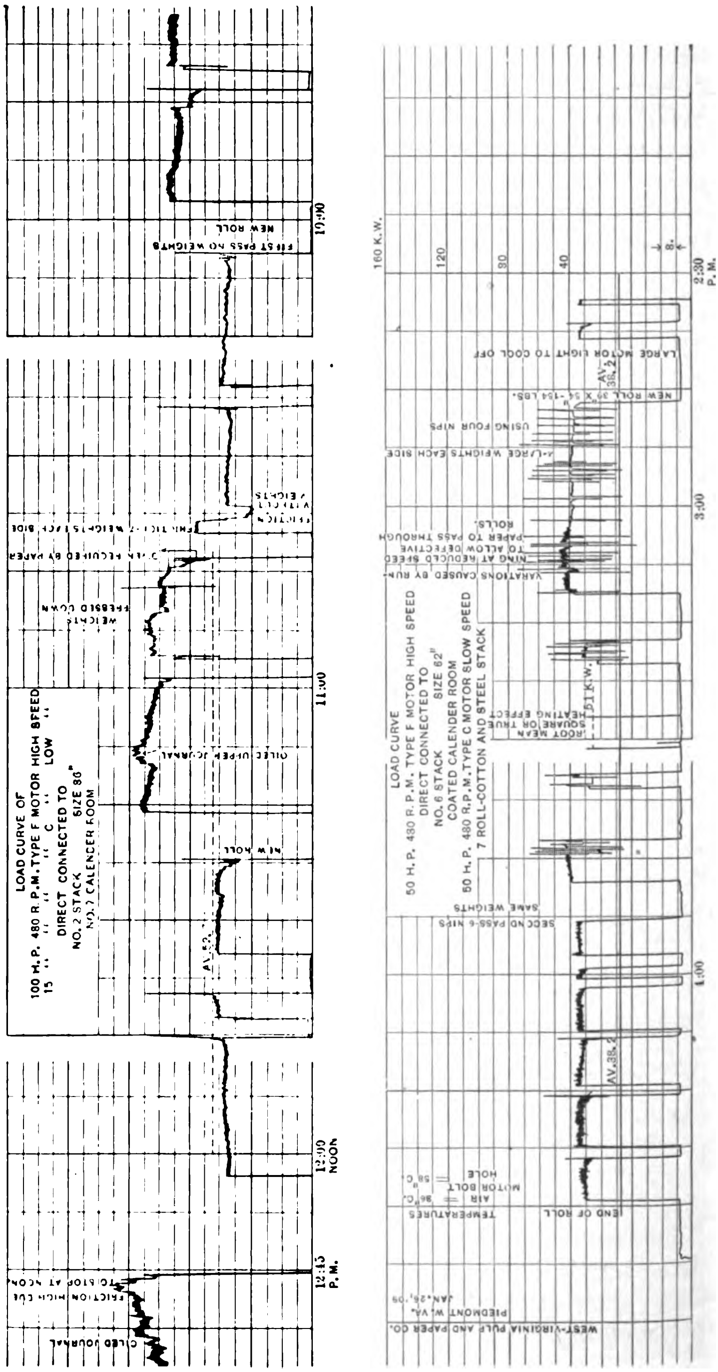

LOAD CURVE OF
100 H.P. 480 R.P.M. TYPE F MOTOR HIGH SPEED
15 " " " " C " LOW "
DIRECT CONNECTED TO
NO. 2 STACK SIZE 86"
NO. 2 CALENDER ROOM
LOAD CURVE
50 H.P. 480 R.P.M. TYPE F MOTOR HIGH SPEED
DIRECT CONNECTED TO
NO. 6 STACK SIZE 62"
COATED CALENDER ROOM
50 H.P. 480 R.P.M. TYPE C MOTOR SLOW SPEED
7 ROLL-COTTON AND STEEL STACK
WEST-VIRGINIA PULP AND PAPER CO.
PIEDMONT W. VA.
160 K.W.
120
80
40
12:45 P.M.
12:00 NOON
11:00
10:00
2:30 P.M.
3:00
4:00

FIG. 8

ing to hardness of the roll, therefore steel or chilled iron requires the minimum power, then comes paper and then cotton. This variation is probably only a few per cent in most cases. A temporary increase of 20 to 25 per cent in the power may be required by a calender when starting up with rolls and bearings cold; this will not usually last more than 15 to 30 minutes and can be taken care of by overload capacity of the drive. It has also been found that a calender takes a little less power as the diameter of rolls is increased, due to the fact that the wedging effect is less.

b. Even though a seven or nine-roll stack is installed, it may be found possible to obtain the finish desired without passing the paper between each pair of rolls. Each pass is known to the paper maker as a "nip." The more "nips" taken, the larger the power, and this increase varies from nearly zero with hard paper to 10 per cent with heavy cardboard for each "nip."

c. Practically all calenders are equipped with plain bearings although roller bearings have been used in a few cases. It is claimed that roller bearings reduce the bearing friction about 30 per cent but the first cost and maintenance is probably higher than for plain bearings. It is also essential to keep the bearings well lubricated, for referring to the top curve of Fig. 8 it is noticed that the power dropped 8 to 10 kw. or nearly 12 per cent when the upper journal was oiled.

d. The amount of power required by a calender will vary according to the thickness of the stock being calendered. This stock varies from the thin book paper to heavy cardboard. The power required for the heavier grades of board may be from 25 to 30 per cent more than for the ordinary weights of book paper. It is not customary to use as much pressure on the heavy cardboards as on the thinner papers. The power requirements for different grades of papers of approximately the same thickness do not vary to any extent. There is also very little difference in power consumed between plain and coated papers.

e. As the power consumed by the rolls alone of a calender is used in overcoming rolling friction, it is correct to assume that it will increase about in proportion to the pressure. The total load consists not only of the friction of the rolls but also of the roll bearings and driving mechanism; which friction will not increase directly with the pressure on the rolls. For all practical purposes, however, as regards the motor sizes, it is safe to assume that the torque will vary directly with the pressure applied to the

rolls. Tests made in Germany show that increasing the pressure 3.43 times increases the power 2.74 to 2.78 times. Another variable that now enters is whether the rolls are steel, chilled iron, paper or cotton. The friction of the last mentioned increases somewhat faster than the others as pressure is applied.

f. Approximately 80 to 85 per cent of the power used in a calender is consumed in overcoming the roll and roll bearing friction except in the case of cardboard. Of this, the amount consumed by the bearings is a very small percentage. The friction of the rolls varies directly as the length of contact, therefore with any given design of calender on the same grade and same speed of paper, the power required will vary almost directly with the width of stack, or the active length of roll face, when calendering.

The following table shows that the constant per inch active width remains fairly uniform, the speed being the same.

Active width roll Inches	Constant per inch width Minimum	Maximum
28	0.78	0.97
62	0.905	1.03
72	0.80	0.94
75	0.81	0.987
86	0.93	1.02
Average	0.85	0.93
Total average = 0.89		

The active width of roll is determined by width of paper and this not being known in some of the above cases, probably accounts for the lower values. A constant near the maximum should be used in determining maximum power required by a given calender.

g. The power required by any given stack with same width and grade of paper will vary directly with the speed at which the paper is calendered, assuming same pressure at all speeds. This must be true if a calender is considered as a friction or constant torque machine.

Two Germans found from tests which were recently published that the power required at full speed was 1.95 times power required at 50 per cent speed, while the amount of paper turned out was 1.75 times without weights and 1.81 times with weights. The increase of pressure reduces slippage between rolls and paper, as might be expected.

Summary of Power Requirements

In determining the amount of power required by a calender the maximum should be considered that would be required with paper of full width, making all the passes, running at maximum speed for which gearing is designed, and with all weights on pressure levers. Calenders are usually designed so that the maximum pressure per inch width is constant. If the above points are considered, then the overload capacity of the drive should be capable of handling any increase in load due to poor lubrication and different roll material. (This applies to paper only, as power required for cardboard is materially different). Tests have shown that the average load on a motor driving a calender is from 50 to 66 per cent of maximum while the true heating effect

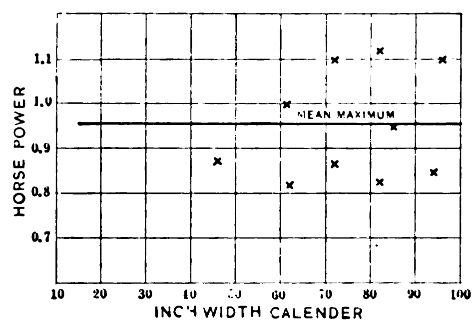


FIG. 9.—HORSE POWER PER INCH WIDTH, CALENDER—500 FEET PER MINUTE.

is from 20 to 30 per cent larger than the average, or from 60 to 80 per cent of maximum.

Fig. 9 shows the maximum horse power per inch width required on ten calenders varying from 36 to 86 inches, reduced to a 500-foot per minute basis. The low points recorded are probably due to narrow paper in the calender. Unfortunately, complete data as to what weights were used are not available on all the tests. This might also account for some of the low points. It is probable, however, that a value of 0.95 to one h.p. per inch width is the correct constant to use at 500 feet per minute calender speed, and if used, the drive will be of sufficient capacity to drive the ordinary calender finishing paper with practically all the weights on pressure levers. Fig. 10 is convenient for quickly ascertaining the size of motor for any width calender

at any common speed and is based on numerous observations and tests.

The question will probably be asked, "Why not choose the capacity of the motor such that full load on the motor will be the same as the true heating effect of the load, that is, from 60 to 80 per cent of that shown in Fig. 9?" Maximum production is desired by the manufacturer and an alternating-current motor having 4 per cent slip at full load will have 6 to 7 per cent, at least, at 40 per cent overload, and this means a loss of 2 to 3 per cent production if the motor is operated at overload while calendering paper, as well as increased stresses in the motor.

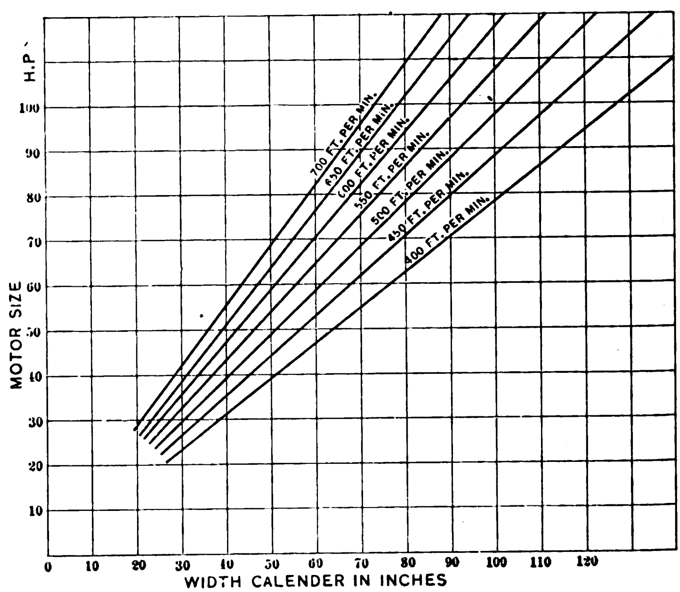


FIG. 10.—POWER REQUIRED BY WEBB CALENDERS.

Power Required by Cardboard. The power used when cardboard is calendered depends largely on the personal element of the mill and on the condition of the stock as it comes to the calender. For a slow speed of about 60 ft. per minute a 10-h.p. motor is required, while the power requirements for high speed should be studied for each particular situation, inasmuch as the power required may easily be 25 to 30 per cent more than for the same calender if calendering paper. In many cases, however, very light pressure is used on the rolls. The power required by

the calender without the cardboard threaded in is therefore smaller (about 40 per cent of the total), while the power consumed by the cardboard is more (about 60 per cent of the total), and the total load on the motor may be about the same as if the calender was working on paper with heavy pressure on the rolls.

Discussion of Motors and Control for Driving Calenders

As we have previously stated, motor drive for calenders must, to be successful, meet certain conditions as follows:

a. Give uniform " threading in " speed.
b. Give smooth acceleration to maximum speed.
c. Must be possible to easily and quickly slow down and again accelerate.
d. Must be able to operate at various speeds to accommodate various grades of paper.
e. Should be able to shut down motor from various points around calender.
f. Control should be simple and extremely substantial.
g. Should be capable of stopping calender quickly.

Two-Motor Equipment—Alternating Current. Fig. 4 shows in outline the mechanical drive using two motors. For the small motor a $7\frac{1}{2}$-h.p. 850 rev. per min. squirrel cage type of motor is used, which may be provided with an induction type starter, or preferably a small oil switch mounted close to the controller for large motor. For the large motor a wound secondary type is nearly always used and a full load speed of 495 or 580 rev. per min. is required in order to keep the pitch line speed and size of the gears within reasonable limits. This motor is controlled from a drum controller, with external resistance, usually, of such a capacity that the motor may be operated continuously at any speed as low as 50 per cent of the maximum. Occasionally, the resistance is designed for only three- or five-minute service on the slow speeds. In addition, an automatic oil circuit breaker should be installed to protect the large motor and also control circuit to small motor. This breaker should be equipped with an inverse time element relay so that the momentary peak demand for power on accelerating will not trip the breaker.

One of the most satisfactory controls which has yet been designed for a calender drive consists of a panel on which is mounted a set of solenoid-operated switches for main circuit, a circuit breaker with inverse time element relay and an ammeter

for check on power consumed. With this panel is used a modified drum controller and the operation is as follows:

Close the circuit breaker, throw in the small oil switch starting small motor. When ready move controller handle to first notch which closes solenoid switches, and continue to advance handle until the large motor takes the load from the smaller motor. In series with the solenoid winding of switches and first notch of controller, may be inserted as many emergency stations as are desired. If one of these stations is opened the solenoid switches immediately drop out and shut down the large motor and the switches cannot again be closed until controller is returned to the first notch. The small motor remains running but disconnected from the driving mechanism by the pin clutch. It is always preferable to stop calender by one of these stations, which should be mounted at the controller. This control puts the work of making and breaking the current on the solenoid switches, which can be made very rugged and provided with arcing tips. In many mills the number of times the current is broken is 8 to 12 or even more times an hour, and if the calender runs 24 hours a day, six days a week, the switches are called on to break approximately full load current 1100 to 1700 times a week.

The above equipment meets conditions *a* to *f*, leaving now only the quick stop. From calculations based on a 65-in. seven-roll stack, operating at 600 feet per minute, it was found that the flywheel effect of the rolls and mechanism, exclusive of the motor and large gear driven by the motor, was 35 h.p-seconds, the motor 38 h:p-seconds, and the large gear 34 h.p-seconds. The flywheel effect of a motor driven stack is therefore about three times that of a stack driven from line shaft and the time required to stop after disconnection from power is about three times as long. This is not so important on light-weight paper as on heavy weights. An electric break may be attached to the large motor which will overcome its flywheel effect. It appears, however, more satisfactory, and introduces fewer complications to use a mechanical brake on the lower roll outside of the calender housing, this brake being applied by a foot lever extending close to the controller. This brake is usually made so that its operation is very effective and the calender can be stopped even quicker than in the group drive.

Direct Current. The motor end of a direct-current drive is the same as with alternating current with the exception that in some

cases part of the speed control is obtained by varying field strength of the motor. The control is worked out in the same manner as before; in some instances the drum controller is replaced by one of a face plate type. Sometimes a master controller only is used, which controls magnetic switches for handling the current. One advantage with direct current is the fact that dynamic braking can be obtained automatically and the calender stopped very quickly.

One-Motor Drive (*Small Motor Omitted*). Fig. 5 shows that this drive resembles the two motor drive, except that by means of gearing and a clutch the large motor is made to do the work previously done by the small motor. The same type of motor and control is used as before and the same facts regarding flywheel effect and braking are true. The calender is stopped by cutting the power off the motor. If the clutch is thrown out then there is only the flywheel of the calender alone, as in the belt drive. This type of drive so far as is known has never been used with direct current but could be if desired.

One Motor Direct Geared—Alternating Current. In this drive as shown in Fig. 6, the one large motor of the wound rotor type is geared or belted direct to the driving roll. It is, therefore, necessary to decrease the speed of this motor, by inserting resistance in secondary, to $\frac{1}{8}$ or 1/12 the maximum speed in order to obtain the proper "threading in" speed. It is impossible to obtain a stable "threading in" speed in this manner owing to the well-known characteristics of an a-c. wound rotor variable speed motor. If the calender is running without paper at the proper speed and paper is fed in, the friction increases and if this increase amounts to approximately $8\frac{1}{3}$ per cent the motor will stop. With some cardboard this increase in friction has been found to be as high as 60 per cent. It is impossible, in nearly every case, to complete the "threading in" without changing the controller setting, which may mean a third man on the calender. After the paper is "threaded in" the motor operates like any other variable speed motor. The control which should be used with this drive is the one using solenoid switches described under "Two-Motor Drive." The controller must be supplied with a large amount of resistance in order to obtain the very slow speed. The flywheel effect and braking conditions are as in the two-motor drive.

One Motor Direct Geared—Direct Current. If a d-c. motor is used direct geared, the conditions are not quite so bad. A d-c. motor giving a 3:1 or a 4:1 reduction in speed from the

maximum by field control should be used. The power input of this motor is proportional to the load within its speed range and is not constant as in the case of the a-c. motor. It is now necessary to reduce the speed from the full field speed, or $\frac{1}{4}$ the maximum to only $\frac{1}{2}$ or $\frac{1}{3}$ in order to obtain a "threading in" of $\frac{1}{8}$ to 1/12 the maximum speed. Using a commutating pole motor of good inherent regulating qualities, a fairly stable speed is obtained and it will take 33 per cent increase in friction to stop motor instead of $8\frac{1}{3}$ per cent as in the a-c. motor. Therefore, with a 30 per cent increase in friction in "threading in" one would not expect to stop the motor. With paper this increase is much smaller and this speed change would not be troublesome. Another feature is that dynamic braking can be used and quick stopping assured. Fig. 11 shows a control panel for this drive.

Mechanical and Electrical Advantages and Disadvantages of Each Drive

In the following comparisons it should be remembered that the paper maker is primarily interested in cost of production. He is, therefore, interested in mechanical and electrical simplicity, ease of control and operation, small maintenance, minimum labor, minimum power cost per unit output.

It has been found from many tests and observations that calenders are run on slow speed from 25 to 33 per cent of the time; 10 to 22 per cent of the time is consumed in "threading in," varying with weight of paper or length of roll.

The following comparisons are bare statements of facts and it is not the intention to recommend one drive over another. A large advantage for one drive, in some mills, may be insignificant in another.

Group Drive by Motor—Same for a-c. and d-c.

Advantages. With this drive the manufacturer has a constant slow speed, only one motor and starter for entire group, minimum chance of trouble with electrical apparatus. Lower first cost, therefore lower fixed charge per calender.

A 70-in. calender arranged for drive from line shaft costs	$4600
Shaft per calender approx.	100
Share of capacity in large motor for 70-in. calender...	400
Total	$5100

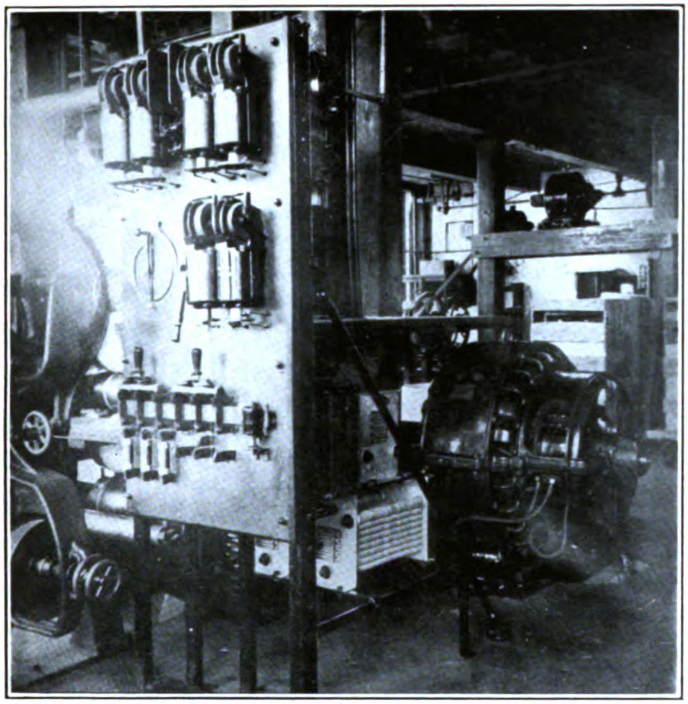


FIG. 11.—DIRECT-CURRENT CONTROL PANEL. [MORSE]

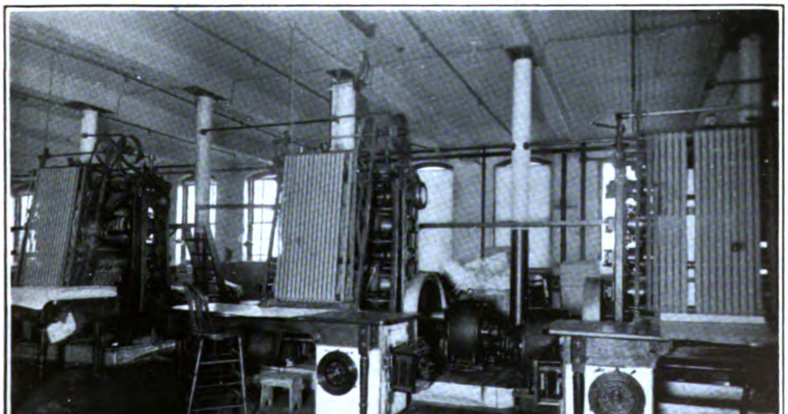


FIG. 12.—SHEET CALENDERS. [MORSE]

Disadvantages. Belts to maintain, two clutches to keep in repair; main shaft takes space on floor below calenders; friction clutch to throw in high speed and as usually operated there is a sudden strain on paper with consequent possibility of breaking and lost production. Only one high speed and no way to vary it. Large motor operating on a widely fluctuating load from 15 per cent to 150 per cent load which means poor efficiency, poor power factor, and a variation in the speed of shaft of 5 per cent or more. It has also been found that the shafting and belting loss alone, per calender, is approximately four kw. This means for a 24-hour day, 96 kw-hr. at $0.01 per kw-hr., $0.96 per day, $288 per year. This capitalized at 5 per cent means $5770.00.

Two-Motor Drive. Same for d-c. and a-c.

Advantages. Constant "threading in" speed, smooth acceleration from slow to high speed, reducing strains on paper and lost production. Ability to slow down to any desired point easily and quickly. Calender can be geared to run at maximum speed that any of paper will stand as slower speeds are available for weaker paper. This speed can easily be 10 to 15 per cent higher than in the group drive. Only one clutch necessary and that a pin clutch. Sometimes a friction clutch is also used on large gear on slow speed so the pin clutch may be thrown in without starting the rolls and the rolls started by friction clutch. Both these clutches are operated from one lever. Large motor operated at good efficiency and power factor. Losses minimum on slow speed. The slow speed motor running light has an average input of 0.6 kw. This corresponds to the friction of the shafting in the group drive, as the large motor does not consume energy except when driving the calender at its operating speeds. Moreover, the efficiency of the motor in the group drive will be nearly the same as this large motor. It may be assumed that this 0.6 kw. is a 24-hour loss, as the small motor is usually left running continuously and is used for "threading in" only 10 to 15 per cent of the time. Thus 0.6 kw. for 24 hr. per day at $0.01 per kw-hr. = $0.144, or $43.20 per year of 300 days—a gain of $234.00 per stack over group drive or 5 per cent on $4700.00.

Good power factor is maintained on the line since the idle current of the small motor is small.

Disadvantages. High first cost: A 70-in. calender,

For two-motor drive	$4750.00
For small motor	170.00
For large motor	900.00
For control	300.00
Total	$6120.00

Maximum chance of trouble exists with electrical equipment. Large floor space is required. It requires three times as long to stop after power is shut off as group driven calender. Large motor requires the same kilowatt input regardless of speed, assuming constant torque. This disadvantage is more than overcome by increased production possible, due to variable speed feature.

TWO MOTORS REPLACED BY ONE. SAME FOR D-C. AND A-C.

Advantages. One less motor to care for than in two-motor drive. Less floor space required, constant "threading in" speed obtained, smooth acceleration from slow to high speed, ability to easily slow down if desired. Calender can be run at maximum speed any paper will stand, as slower speeds are available for weaker papers. As motor and gear may be disconnected from stack on stopping, the flywheel effect same as in group drive. If stack is stopped by cutting power off the motor the flywheel effect same as in two-motor drive.

Calender, 70-in., and mechanism	$4925.00
Large motor	900.00
Control	275.00
	$6100.00

Disadvantages. Two clutches, one being friction; large gear on quill which may wear and cause excessive gear wear. Requires same kilowatt input regardless of speed, assuming same torque. This is turned to an advantage by increased production possible. Light load losses larger. Based on a 70-in. stack, a three-phase 550-volt 75-h.p. motor running light will operate with a current approximately 25 amperes, power factor 15 to 20 per cent, kilowatt input 4.0 to 6.0. Assuming 5 kw. to be average and the motor running light 20 per cent of time or 4.8 hours per day, we have $5 \times 0.01 \times 4.8 = \$0.24$ per day or $72.00 per year, or $28.80 per year more than two-motor drive. This is 5 per cent on $575.00 and small motor costs $170.00. The worst effect is in the power factor of the system if many of these motors

are installed. As far as power consumed goes, there is ordinarily not much choice.

Single Motor, Direct Geared

Advantages—a-c. Only one motor is used, no clutches, minimum possible amount of gearing and smallest floor space of any drive. The calender can be geared for maximum speed that any of the paper will stand and can be easily retarded at will, and operated at slower speeds for weaker paper. Smooth acceleration from "threading in" to running speed is obtained. The first cost is lower:

Calender	$4185.00
Motor	900.00
Control	450.00
Total	$5535.00

Additional Advantages on d-c. Dynamic braking can be used to stop calender quickly. More stable "threading in" speed due to the fact that full field speed is about $\frac{1}{3}$ maximum and the speed has to be further reduced by armature resistance to $\frac{1}{3}$ or $\frac{1}{4}$ instead of $\frac{1}{8}$ or 1/12 as with a-c. Losses are less on reduced speeds than with a-c.

Disadvantages. Very unstable "threading in" speed is obtained; controller setting usually has to be changed during "threading in." Extra large controller and resistance is required to obtain the slow speed. The large flywheel effect causes the calender to run three times as long as if group driven. It has been found on this type of drive that the "threading in" requires from 9 to 14 per cent of total time and on a 72-in. calender the power consumed varied from 16 to 29.8 kw. during this period, as against about 2.2 to 4 kw. with two-motor drive. As this time required to "thread in" is also somewhat longer, the cost of power used for the "threading in" process is from 6 to 10 times that of the other two types of drive. This motor is practically never running except when paper is in the calender, and therefore has no "running light" loss to correspond to the other drives. The power factor is low while motor is running light and during "threading in." The control for this drive is subjected to the hardest service of any, as 60 per cent to 100 per cent full load current is broken every time the current is shut off. Motor tests show that the current is broken 13 to 15 times per hour as an average. This means for a 24-hour day, six-day week, 1870 to 2160 breaks per week. The ordinary

circuit breaker contact is said to be good for about 3000 breaks, so a very substantial switch must be used in order to get any reasonable length of service. This drive may require more labor, or in other words a third man may be needed at controller during "threading in." This same man, can, however, take care of several stacks.

Why Should Motor Driven Supercalenders be Used?

From the preceding pages certain advantages of motor driven supercalenders have been pointed out which tend to lower cost per unit product and to increase the production per machine. These may be summarized as follows:

a. Long mechanical transmissions eliminated with maintenance of their shafts, belts, hangers, etc.

b. Reduced chance of all calenders being shut down at once. With mechanical drive this often happens due to belt breaking or shaft trouble and the loss of production is large.

c. Smooth acceleration from slow to high speed, reducing strains on paper, therefore reducing breakage and loss of production.

d. Ability to operate calender at maximum speed which the particular paper will stand. With group drive only one speed is available.

e. Ability to easily slow down for a weak place in paper saves much time and increases production. Referring to Fig. 8 (lower half) it will be seen at one point the paper ran 25 minutes without a break but the controller was used 26 times to reduce the speed and it is further seen that it requires on the average three to five minutes to paste together the paper and feed it in again. If the paper had broken 13 times only it would mean

$$\frac{13 \times 4 \times 500}{3} = 8700 \text{ yards of production lost.}$$

f. The speed of calender is much more likely to be uniform, as in group drive the number of calenders operating varies the belt slip and speed of line shaft.

g. The kilowatt-hours per unit output required are less than in group drive.

h. The power factor of system is better than when large motor drives group, if a two-motor drive is used.

i. That the above facts are true is proved by figures of one of the largest and best managed mills in the United States which give the average efficiency of all motor-driven calenders as 35 per cent better than group driven and of two of the most recent drives, 50 per cent better.

Sheet Calenders

Use. A sheet supercalender is used to give "loft" dried papers their final finish where that finish can be given by passing the paper between rolls, as contrasted to finish given by platers. It is also used in certain machine-dried papers to give the final finish after they have been cut into sheets.

Construction. Fig. 12 shows motor driven sheet calenders taken from the feeding-in side. The strips of webbing run vertically in front of the calender. These endless bands run around a system of rollers. There is a set of these bands on both the front and back of the calender and they serve to take the sheets from the operator feeding in, guide them through the rolls and deliver the paper after it has been calendered to the " catch box " and to the operator taking care of the finished paper.

The general mechanical construction of a sheet calender is similar to a webb calender, except that it is lighter. The widths commonly used are from 26 to 48 in. and the stacks are from three to five rolls high, the five-roll stack being the most common. On these, as in webb calenders, the top and bottom rolls are of steel and larger than the others. The intermediate rolls may be either steel, chilled iron or fabric.

Sheet calenders do not require a slow speed for " threading in " so they may be driven direct from the power supply to a pulley or gear mounted on the lower or driving roll.

The paper is finished under pressure which is applied by screws at the top of the stack. This pressure is varied according to finish desired and kind of paper being calendered.

Power Required. The power required by a sheet calender varies according to the same laws as were discussed under webb calenders. The power required by a five-roll, 36-in. calender will be discussed, as this is the most common size in use. This calender requires from $2\frac{1}{2}$ to 3 h.p. to drive the rolls, without pressure on them or paper going through, at a surface speed of 400 feet per minute. By means of the pressure screws this power is increased to 9 or 12 h.p. for ordinary work and can be increased to as high as 18 or 20 h.p. The following table shows the power required by this size calender for various papers:

Paper	Friction h.p.		Paper h.p.	Total h.p.
	No pressure	Usual pressure		
20 lb. flats, 17 × 22 in.	—	$5\frac{1}{2}$	1	$6\frac{1}{2}$
32 lb. flats, 17 × 28 in.	—	6	3	9
No. 4 Bond, 24 × 32 in.	3	10	4	14
Heavy envelope 24 × 38 in.	$2\frac{1}{2}$-3	9-10	$2\frac{1}{2}$-3	$11\frac{1}{2}$-13
170 lb. paper $30\frac{1}{2}$ × $29\frac{1}{2}$ in.	$2\frac{1}{2}$-3	10	$7\frac{1}{2}$-10	$17\frac{1}{2}$-20
300 lb. paper 31 × 26 in.	$2\frac{1}{2}$-3	10	10-14	20-24

Fig. 13 shows a typical power curve taken from a 42-in. five-roll calender with a speed of 400 feet per minute. Comparing this with the above table it will be noted that the same paper takes practically the same power whether the calender is 36-in. or 42-in. width. A sheet calender should be run at the highest speed at which the operator can feed in the paper and not have any space between the sheets. These spaces are shown in Fig. 13 where the power drops to the friction load. The size of sheets and the weight of paper determine the speed with which any given operator can work, but this speed is not necessarily the same with the various operators. It is obviously a waste of power to run the calender too fast for the operator and a waste of the operator's time and of production to run the calender too slow. This shows that the motors driving sheet calenders should be adjustable speed and the range of speed is determined by the

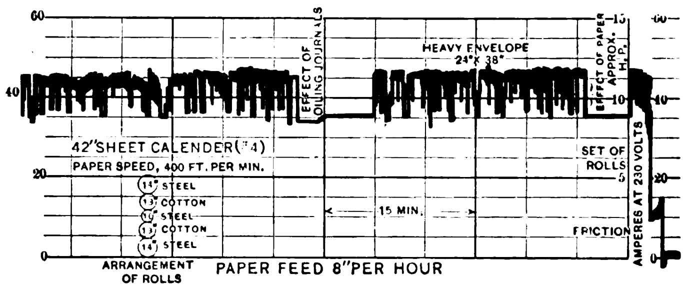


FIG. 13

range of grades of paper to be finished. The maximum possible speed seems to be about 500 feet per minute and the minimum speed ever necessary is 200 to 250 feet per minute. Usually a range of about 30 per cent is sufficient. The following motor sizes appear to be about correct for five-roll calenders at 400 to 450 feet per minute maximum speed:

28 in.	15 h.p.
36 in.	15 h.p.
42 in.	20 h.p.

Methods of Drive. With group drive it is not possible to vary the speed of the rolls to suit the operator or paper and the production per calender is less than it should be. Direct-current motors have been used in many mills very successfully. A commutating pole motor of approximately 700 to 800 rev. per

min. should be used, direct geared to the bottom roll. This motor should have a speed reduction of at least 30 per cent by field control, keeping in mind that it is driving a constant torque load.

It was not thought feasible to use a-c. variable speed motors until recently, when a test was run using a 15-h.p., 850-rev. per. min., wound-rotor type with a speed reduction of 50 per cent by insertion of resistance in secondary. This test proved that excellent results could be obtained using such a motor, and there is no reason for hesitating to install a-c. adjustable speed motors on sheet calenders anywhere. The most satisfactory way to equip a group of sheet calenders with a-c. motors would

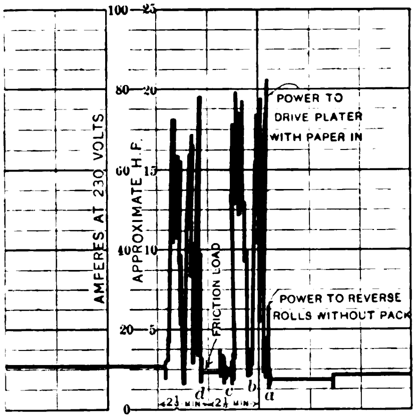


FIG. 14.—POWER CURVE OF 36-IN PLATER.

be to drive part by constant speed motors and part by adjustable speed motors, as in every case the work could be so laid out that the constant speed calenders could be working at their best efficiency and the special papers finished on the adjustable speed calenders.

PLATERS

Use. In nearly every mill making a high grade finished paper there will be found a machine known as a "plater." This machine is used to put certain kinds of finish on the paper after it has been cut into sheets. Probably the most common finish is the so-called "linen finish" which is found so often on writing papers. This is obtained by making a stack of paper with sheets of linen between the sheets of paper (at the

top and bottom of this stack are pieces of zinc) and passing this paper through between the rolls, under pressure, several times. In the packs the linen may be replaced by sheets of any other material which will impart the desired finish to the paper. This may be either some kind of fabric or even metal sheets.

Construction. The general construction of the plater is as follows. The machine consists primarily of two steel rolls, operating under pressure, a table on which the pack is laid, and the driving mechanism. The driving pulley consists of two tight and one loose, as it is necessary to reverse the rolls with each pass of the paper. Originally, platers were constructed with a minimum space of one inch between the rolls and an adjustment of three-quarters of an inch. With the increased use a demand was made for a wider opening and more adjustment. By a careful design and arrangement of the gearing it is now possible to obtain an adjustment from zero to two inches, or, from any desired minimum opening, an adjustment of two inches.

The size of plater in common use has two rolls approximately 17 in. in diameter and a working length of 40 in. By means of weights and a system of levers, a pressure as high as 40 tons is applied to the rolls. Platers are built as narrow as 36 in. and up to a maximum width of about 48 in.

Power Requirements. Fig. 14 shows a typical power input curve for a 36-in. plater. This is an ordinary belted plater and the motor is belted to the countershaft. There is also a large pulley on this shaft which has considerable flywheel effect and helps out on the peaks a certain amount. This plater has a pressure of about 40 tons, and a surface speed on the rolls of about 61 feet per minute. It will be noted that about 10 amperes or approximately $2\frac{1}{4}$ h.p. was required to drive this machine light, but that it jumped to 80 amperes or approximately 20 h.p. at (*a*) when the pack was inserted. It can be seen from the fluctuations about how many times the rolls were reversed. The pack is not allowed to pass entirely out from between the rolls before reversal. At (*b*) the pack is turned around to make sure that the finish will be the same on each edge. At (*c*) the pack is finished, removed, and a new one started at (*d*). It takes about two minutes to finish a pack and about as long to change packs. The average load while plating is about 15 h.p. but the load factor on the motor is very poor.

In a group drive having four or more platers it is safe to choose a motor allowing about 10 to 12 h.p. per machine. If the platers

are to be driven by individual motors from 15 to 20 h.p. should be used.

Method of Drive. Nearly all platers up to the present time have been driven by a belt from a line shaft. It is a simple matter to use a motor belted to this line shaft.

Many paper makers would like to obtain an individual drive on their platers. Considerable time has been spent in trying to obtain a motor and a reversing switch which would stand this service. This means about five reversals of the motor a minute and in order to obtain this number it would require a motor of small flywheel effect but large torque. In order to obtain quick reversal it would be necessary to "plug" the motor, that is, apply the power for reverse direction before the motor stopped. No one has as yet had the courage to attempt this on a standard 40-in. plater. There are three platers of a small size taking paper pack 9 by 14 by $1\frac{3}{8}$ in. with rolls set at one-inch opening, driven by a d-c. 5-h.p. 400-rev. per min. commutating pole motor, direct geared and reversing with each reversal of the pack. These have been operating several years with the best of results. It is reasonable to suppose that the same thing could be done with larger motors. The big advantage to be obtained with individual drive on platers is doing away with shafting and belts with their attendant dirt and grease, and the maintenance and replacement of the plater belts, which wear out very rapidly. It would also give a greater flexibility in the finishing room. A group drive will give a much lower first cost, smaller motor, better load factor, better power factor if alternating current is used, and better efficiency of the motor.

Conclusion

From the preceding pages it is quite evident that increased quality and quantity of production is obtained by the use of electric drive in the finishing department. This is due to the fact that each machine is operated, and each kind of paper finished, at the correct speed.

A paper presented at the 29th Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June 28, 1912.

ELECTRICITY ON THE FARM

BY PUTNAM A. BATES

Never in the history of this country has there been such a great arousing of public opinion, such an arousing of interest of the people generally, in the agriculture of the country. We are commencing to appreciate that while in the early years of the past century two-thirds of our people were engaged in the producing business, producing food and clothing for the people, now but one-third are so engaged. And it also seems to be pretty clearly demonstrated that the average earning of the average farmer has netted too small a return for his labor. In many parts of the country, what he did earn was earned at too great a personal sacrifice—labor for long hours and no recreation. Plainly speaking, we have wakened up to the situation that though the yearly crop figures seem to indicate an abundance, we are actually approaching the condition where demand will soon exceed supply, and in most instances the farming business is badly out of gear and needs reorganizing. It has fallen to the lot of the electrical engineer to take a hand in many matters of reorganization, and I believe agriculture now requires his attention.

Betterment of the farmers' conditions and improved efficiency in all the operations involved in his work is the cry of the day. Bankers and business men's associations, federal departments, agricultural colleges and important engineering organizations are giving this feature of the country's welfare careful study, and yet there is perhaps no one improvement that may be counted upon to so radically benefit the farmer as the introduction of electricity on the farm.

The electric farm, however, is not a new idea, for several farms well worthy of this name have been in successful operation for

some ten or twelve years, and perhaps longer than this. But there has been very little organized effort in disseminating existing knowledge of the practical use of electricity in agriculture, with the result that farms so equipped are generally regarded with suspicion and possibly in the light of a hobby.

I shall endeavor to show that such a point of view may at once be dismissed and we may look for a general use of electricity on the better class of farms in this country before many more years have elapsed. As a matter of fact, electricity is now being utilized for lighting and power purposes on a much larger number of American farms than perhaps many of us have heretofore realized.

Let us consider for a moment the farms of our great Southwest. In some sections of that wonderfully fertile country, well protected by the high mountain ranges, practically every farm is an electric farm. That is, to say, the buildings are lighted by electricity and many of the laborious operations are accomplished by the use of electric power. These really were our first electric farms, the period of their establishment corresponding with the development of the water powers of the nearby mountains.

On the majority of these farms irrigation is practised and quite naturally electricity was first made use of for pumping purposes. Then under the influence of progressive local central station operators, it was almost universally adopted for light.

I can recall seeing electric lights and the electric flat iron in use in the farm homes on the Pacific Coast, eleven years ago. The people were content to enjoy the advantages which these improvements made possible to them, but did not seem to regard their conditions as unusual. Their farms were in fact electric farms and their industries dependent upon the produce of the land were, as they are now, practically all operated by electricity. I refer to the canneries, fruit packing houses, etc.

The conditions surrounding the farming districts in Southern California, for example, at that time, were such that any other form of energy would have been unusual to adopt, a combination of circumstances being largely responsible for this happy situation. The high-tension transmission service systems were then new and the companies desired business; besides this, we did not have the gas engines we have today. The efficient and reliable gasolene and fuel oil motors were not developed until several years later. There was pumping to do, for irrigation was rapidly coming into favor, and, naturally, the electric companies secured this business.

It is hard to say whether the power plants, supplying service at rates within the reach of all, made the irrigated farms, or the electrical load, which these farms offered, insured the success of the power developments. Both interests seem to have worked together and in some instances practically the entire supply of the central station current was at once engaged for lighting, heating and power uses on the farms. This was the case ten years ago in the instances I speak of, and according to reports I have just received, the situation has not materially changed,

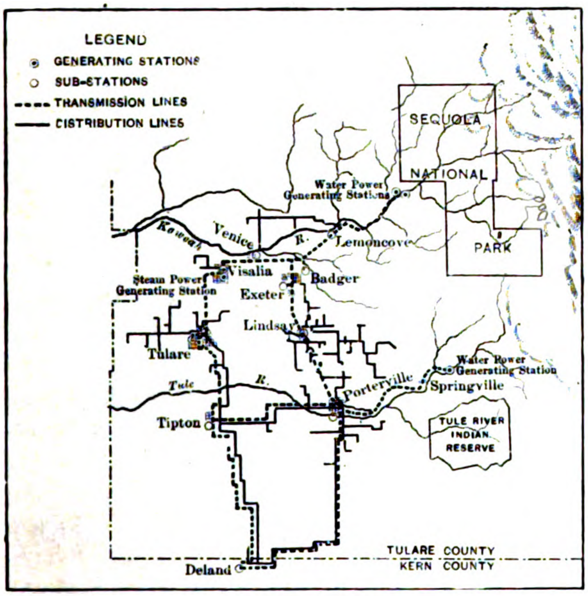


FIG. 1.—TERRITORY COVERED BY MT. WHITNEY POWER & ELECTRIC CO'S SERVICE, VISALIA, CAL.—TYPICAL OF A MODERN INTENSIVE FARMING DISTRICT.

except that both supply of and demand for the current have increased.

Such electric service plants may be regarded as "farmers'" central stations and I shall commence my illustrations with a description of the Mount Whitney Power and Electric Company's service in the vicinity of Visalia, Cal. This will serve as an illustration of a plant of this class.

Description of the power station itself or the transmission system is not necessary as the plant is well known, and possibly many readers are familiar with its equipment. Fig. 1 shows the

territory covered by the service of this company and is typical of a modern intensive farming district where irrigation plays an important role.

Some of the farms in this district are large farms of several hundred acres, but the majority are small truck and fruit farms, ranging from 10 to 40 acres, an average of about 20 acres to each person, the total number of acres irrigated by electric power from the Mt. Whitney plant approximating 25,000, and representing about 6000 horse power in electric motors.

Fig. 2 shows a characteristic pumping installation employed on the irrigation farms in this district. It is interesting to note that on this 800-acre farm the electric service lines have been carried to several widely separated points, serving pumping motors in some cases of no greater capacity than five horse power. In fact, the loads these western central stations cater to, oftentimes, are of surprisingly small amount and quite distributed.

In the Exeter district, where this 800-acre farm is located, there are 32 plunger pumps aggregating 96 h.p., and 16 centrifugal pumps aggregating 125 ½ h.p. And in the Lindsay district, comprising about 25 square miles, there are in operation 217 pumping plants with a total connected horse power of 1794, of which 113 were plunger pumps (1100 h.p.) and 104 centrifugal pumps (694 h.p.) The total pumping load connected to the company's system is 374 plunger pumps (2385 h.p.), and 256 centrifugal pumps, (2471 h.p.) or a total of 630 pumping plants with 4856 h.p., being on the average 7.7 h.p. for each pumping plant.

The irrigation pumping season in California is from five to six months at 24 hours per day. Contracts are on a basis of $50.00 per annum per horse power; the customer installing and maintaining at his own cost the motors, transformers, pumps, housings and all other appliances. He agrees to pay each year the sum of $50.00 for each horse power furnished him at time of his maximum consumption during the year. He further agrees that the amount of power to be paid for at that rate shall not be less than 75 per cent of the rated horse power of the motor. Motors of less than five h.p. are paid for at $50.00 per year for the rated horse power of the motor, instead of 75 per cent thereof.

In very few cases only, power is sold between the hours of sunrise and sunset at $30.00 per h.p. per annum, the company not having much power to sell at this rate as, during the irrigation

season, the irrigators want to operate day and night. However, small power applications are taken care of in this way, consisting chiefly of cream separators, churns, grindstones, wood saws, heating flat irons, washing machines, fans and other domestic items.

There is also a partial meter rate contract which is used principally by growers of acidulous fruits and alfalfa, the essential points of which are as follows:

Current is furnished during the six months, February 1st to August 1st, at $25.00 for each horse power based on maximum demand, while for current furnished during the remaining months of the year, the rate is three cents per kilowatt hour, it being agreed that the maximum amount of power to be used during the meter period will be equivalent to at least $6.00 per horse power per month of motor rating.

The straight motor rate is used for development work, grading from five cents for the first 26 kilowatt-hours per month (additions depending on size of the motor and the months), usually ranging around one and three-fourths cents to two cents per kilowatt-hour per month. Most of the irrigating power, however, is sold on the $50.00 flat rate.

The farms served by the Mt. Whitney system may be termed electrically irrigated farms, as in all cases the farmer operates his irrigation pumps by electricity. The details of this class of business it will be seen are well established. Electric companies in other sections have also built up businesses of this kind and in doing so have followed the same lines or a modification of them.

Another hydroelectric development and distribution system where irrigation pumping forms an important portion of the total load is that of the Pacific Power & Light Company.

The lines of this company traverse a fertile farming district lying in the southeastern corner of the State of Washington, just east of the Cascade Mountains. Several power developments are connected together making a complete distribution system, serving a total population of 101,900, including 39 towns, having an average population of 2500. In addition to the towns, the population of the rural communities is 5000.

There are 300 miles of primary lines at 66,000 volts, with 500 miles of 6600-volt secondary.

All of the plants making up this company's system are illustrations of a generating station designed to meet the lighting

and power demands of a growing farming community. Fig. 3 shows the territory served.

It will be seen from this map that the power plant at Naches is close to the mountain range and Figs. 4 to 8 show the evolution from the snow capped mountains to the power station where the energy of the falling waters is utilized first for generating electricity and then allowed to pass on, to be used again for irrigation.

These illustrations require very little description, for the development shown is complete. It is a beautiful illustration of the combination of the works of God and man. The magnificent orchards and gardens which have thus been made possible

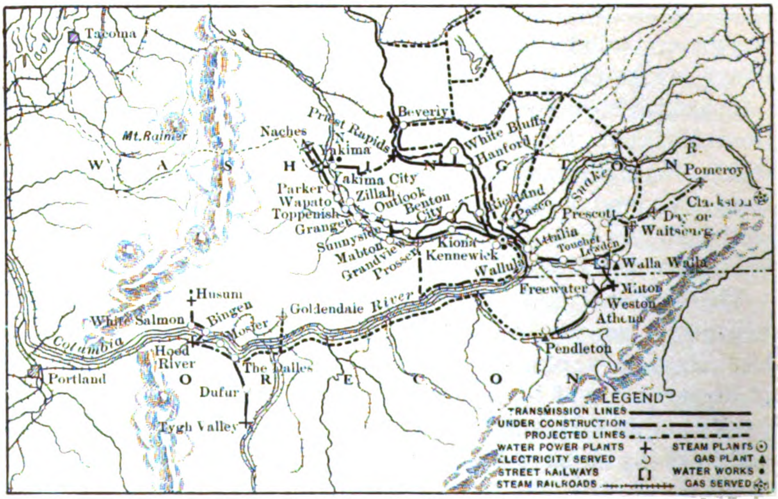
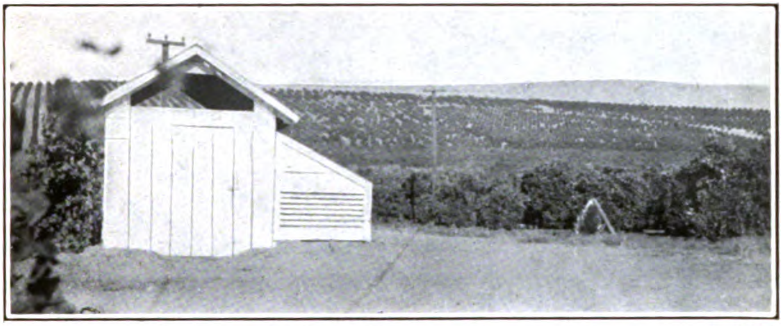


FIG. 3.—TERRITORY SERVED BY SEVERAL POWER STATIONS OF THE PACIFIC POWER & LIGHT CO. IN AN IRRIGATED FARMING SECTION, WASH.

on the waste places of the earth are wonderful accomplishments of which we may well be proud. There can be no greater work for us all in this day of agricultural investigation, than to advance in all parts of our land the utilization of our resources as exemplified by these illustrations.

Figs. 9 and 10 show further developments in electric power transmission, and 11 shows the acres of garden truck and the bountiful crops of hay or grain that result from the scientific application of water to the fertile soil.

During the early part of the history of American farming there was too much extensive husbandry and not enough in-



[BATES]

FIG. 2.—800-ACRE FARM AT EXETER, CAL.

Pump house containing 5-h.p. electric motor, belted to $5\frac{1}{2}$ in. by 5-in. triple plunger pump with $3\frac{1}{2}$-in. suction, using 5.56 h.p.

[BATES]

FIG. 4.—MT. RAINIER, THE FOUNTAIN HEAD FROM WHICH DESCENDS A NEVER FAILING SUPPLY OF WATER.

FIG. 5.—NATCHES RIVER ABOVE INTAKE OF CANAL. [BATES]

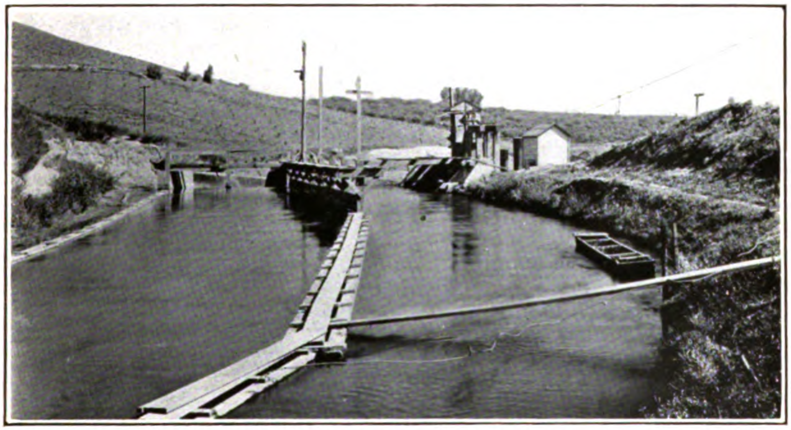


FIG. 6.—CAPTURED WATERS—FOREBAY OF NATCHES POWER CANAL. [BATES]

FIG. 7.—PIPE LINES FROM CANAL TO NATCHES POWER HOUSE. [BATES]

FIG. 8.—NATCHES POWER HOUSE. [BATES]

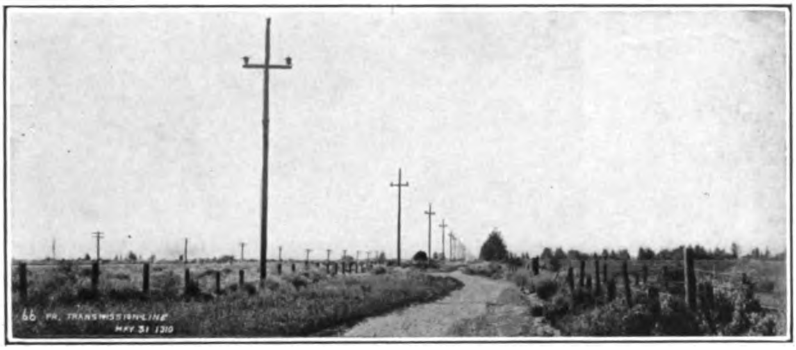


FIG. 9.—POWER TRANSMISSION LINE. [BATES]

FIG. 10.—AN IRRIGATION COMPANY'S PUMPING PLANT ON THE COLUMBIA RIVER. [BATES]

Two 50-h.p. motors driving centrifugal pumps supply gravity ditch furnishing water to many farms. These recently supplemented with a 625-h.p. vertical type centrifugal pump to supply a new high-level canal.

tensive farming. Land was abundant and cheap, and much of it drained itself. The pioneer, believing the supply of land inexhaustible, selected a patch, killed off the trees, cultivated it until the fertility of the soil was exhausted, and then moved to another location. In this way, the increase in population being enormous, great and rapid inroads were made on the country's natural resources of soil. In time, all the naturally drained and naturally watered lands became absorbed, and a great deal of it exhausted, temporarily at least.

The reclamation of our western desert and prairie land along most approved scientific lines is an object lesson to us all. Those lands are now rapidly being taken up and have become very valuable, and fertile, low cost farms by the tens of thousands are needed.

We have learned from these western developments that for proper crop culture all lands must be drained and all crops need water. And it is not sufficient to have a deluge of water from time to time, but water must be applied in such manner as to provide the food necessary to plant life, in order that development may be greatest at certain stages of its growth. This is especially interesting, in that it is a claim for the merits of irrigation, not only in the arid country, but also in sections where there may be an abundant rain fall.

Mr. C. J. Blanchard, Statistician of the U. S. Reclamation Service, in a lecture on "Making the Wilderness Blossom,"* states that the desert of our old geographies has no place on the map. The magic of irrigation has transformed valleys long vacant into prosperous agricultural communities.

A brief summation of the work accomplished shows that construction is under way or has been completed on 29 projects involving an expenditure of $65,470,000. In the eight years of actual work there have been dug 7000 miles of canals and more than 19 miles of tunnels, mostly excavated through mountains. The total excavation of rock and earth amounts to 77,200,000 cubic yards. There have been built 570 miles of roads, 1700 miles of telephones, and there are now in operation 275 miles of transmission lines over which surplus power and light are furnished to several cities and towns. The small farms and villages grouped about these developments give the effect of suburban rather than rural conditions. The cheap power developed from the great dams or from numerous drops in the main canals

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is now utilized for the operation of trolley lines which reach out into the rural districts bringing the farmer in close touch with the city. It runs numerous industrial plants, for storing, handling and manufacturing the raw products of the farm. The same power is used for lighting and heating in the towns and for cooking in the homes. On several of the projects the farmers are applying for electric power and in many farm houses electric power is utilized for many domestic duties.

More than a million dollars has been invested in the development of power on the Salt River project, of which the farmers have voluntarily raised $800,000. The sale of power up to the beginning of the present year amounted to $144,000 with the plant only partially constructed. This revenue will contribute materially towards lessening the cost of operating the irrigation system.

Thus it may be seen that scientific agriculture, irrigation and electricity have formed a powerful combination. The natural waters are played with at will, sometimes passing directly to the land, but more often the turbulent mountain streams are carried for miles in flumes or canals, only to give up energy at several points on the way, and ultimately to irrigate the land by gravity, or pumping, as the conditions may require.

Another method is to drain the marsh land and pump the water thus available on to the higher places adjoining. Suitable crops are then grown on land of any level with the result that the area for production is materially increased.

In many of our states, both East and West, there is a well established underflow of water which can be made available through pumping. In the sections where irrigation methods obtain, water ditches conveying this well water to various portions of the farmer's land are often carried to the next man's land, the compensation thus derived diminishing the pumping cost.

All through our Western and Southwestern country are to be found examples of well installations where electric power has replaced steam or gasolene engines, for it becomes economy to do this under the favorable rate charged by the electric generating stations there.

The San Joaquin Light and Power Corporation of Fresno, California, supplies electric service to seven counties in one of the most fertile farming sections of the country, the actual area being more than 200 miles long and 75 or 80 miles wide. This,

therefore, is a very important district, and information regarding its growth and present conditions cannot help but be of value.

Mr. A. G. Wishon, general manager of the company, reports as follows:

We are now serving 140 pumping plants in our territory, which are used for the development of water for irrigation purposes. We wish to mention particularly a number of plants that we are operating for a water company located at Alpaugh, Tulare County, California. This proposition is somewhat unique. About twelve miles from a colony of 8000 acres, planted to alfalfa and various other farm products, are located seven artesian wells that are about 1000 ft. deep. These wells were flowing artesian wells, the capacity of which was about 60 in. per minute, per well. This water company made a contract with us to extend our transmission line to this nest of wells, which are located on a tract of about 10 or 15 acres, for the purpose of serving electricity to operate electric motors. There were seven 20 h.p. motors installed at seven different wells, belt-connected to 8-in. pumps. These pumps are located at the surface of the ground, with a 30-ft. suction pipe; each pumping plant is delivering about 1500 gallons of water per minute, with about 20 h.p.

They are paying us $50 per h.p. per year for continuous service, the motors being operated almost continually throughout the entire year. The water discharged flows into a main canal which extends to the colony twelve (12) miles away, and at a point near the edge of the colony, this entire body of water is raised about 6 ft. with a 50-h.p. motor and distributed over a tract of 8000 acres. They are also paying us the same price per h.p. per year for the 50-h.p. motor. The cost, therefore, for irrigation is about $1.25 per acre, which is a very reasonable charge for water service throughout the entire year. These people are raising 10 or 12 tons of alfalfa per year, per acre, and in some instances the onion growers will clear $500 per acre.

Irrigation is the key which unlocks the fertility of the soil, and to comprehend its importance in agriculture, one must appreciate the fundamental principles governing plant growth and soil culture.

Rain may or may not come when it is needed most, and again, it may pour forth even in destructive quantities, but water under a well-managed irrigation system is turned on when and where required. This makes farming in so-called arid land a more definite and scientific proposition than it is in parts of the country apparently more favored by nature. When we have so arranged our soil conditions that water may be drained off the land as positively as it is applied, the application of irrigation methods are beneficial, no matter what may be the natural conditions of rain fall.

Pump irrigation results in intensive farming. And this is the direction in which our agriculture is moving. It may

also be added that the power required for pumping has proved to be the opening wedge in introducing the use of electricity in the majority of those farming districts where dependence upon this form of energy has become established. The most scientific farming can be done only by pump irrigation where the work can be arranged and the farm run just as systematically as some of the big manufacturing and commercial undertakings.

Regarding irrigation in humid districts, Mr. Milo B. Williams,* Irrigation Engineer of the U. S. Department of Agriculture, states that it is the distribution of rainfall with respect to need of different crops which determines the necessity for irrigation in a locality. Drought records for several years past have led the National Department of Agriculture to encourage supplemental irrigation in the humid regions as a vital factor in crop insurance.

The most humid portion of the agricultural East is subject to the greatest irregularity of rainfall. This refers to the southern states bordering on the Gulf of Mexico and the Atlantic Ocean. Here the normal annual precipitation ranges from 45 to 55 inches and yet these states are subject to droughts lasting from 20 to 60 days or more during the growing season. Irrigation in various parts of Alabama, Georgia and Florida, has resulted in producing very profitable crops on land which has heretofore failed to yield sufficient returns to pay for cultivation. Irrigation will do for the south what it has done for the west. It will insure results to the small farmer. The coming of the small farmer to the south will cause the passing away of ruined plantations, as his going to the west has caused the passing away of great deserts and wasteful wheat ranches.

The South today represents one of the largest areas of dormant latent agricultural possibilities in this nation and when drainage of the low lands is coupled with the general practise of irrigation throughout our South and our East, much in the same way that water distribution has been conquered in our West, we will have added many millions of acres to the productive area of this great country.

These are great problems and promise an immense work for years to come, but the beneficial results will outweigh many times the cost and labor that will be necessary to bring them about. At present, an abnormal condition exists just as it did in the arid sections before irrigation was practised, and it is the writers' opinion that the reclamation of the worn out farms and the barren

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lands of the Atlantic Slope presents agricultural opportunities unsurpassed at this time by any section.

In the drainage of water soaked lands, as in irrigation, electric power may be used for short lift pumping. And as an indication of the magnitude of the work ahead of us in this field alone, it is sufficient to quote from the statistical records of the United States of 1910 issued by the Department of Commerce and Labor, which place the total swamp area and overflowed lands at a total of approximately 75,000,000 acres.

In their present condition, the swamps of the country are a source of weakness in our national economy. They are unproductive, but they can be made sources of great national wealth.

The policy of maintaining our agricultural lands in vast areas and thus, through what has been termed " extensive husbandry," failing to utilize to the utmost every acre of fertile soil, is rapidly falling into disfavor. And we are, on the other hand, moving toward an increased number of farm homes with more intensive methods of development. This change is going on all over our land. In the West, the old cattle ranges are passing away, merely to be replaced by irrigated farms, where diversified methods are practised.

The stock feeder of today makes his money on the weight of the stock when purchased, the practice being to buy in the fall, feed through the winter and sell in the spring. Such increased weight as live stock make in that period, however, is not sufficient to pay for its portion of the feed given. Profit, therefore, comes through improved condition of the meat, and the difference between fall and spring values. The successful feeder aims for an increase of about 100 per cent.

To accomplish this, care must be exercised in feeding. The coarse and unbalanced rations which cattle had to depend upon on the ranges, proved anything but beneficial to them, particularly, out of the growing seasons. The method today is to use grains with the roughage, and to grind the grains and cut the roughage. For this the farmer must have power—in fact to meet competition the farmer must economize on his feeding, that is, he must work for the best results with the least expenditure for feed—power for cutting and grinding is now a necessity on every stock farm of any appreciable size, for with feed so prepared, there is better assimilation and less waste.

Of late years, an enormous impetus has been given to alfalfa grinding and corn cutting for ensilage. Feeders have found that

by following this method the cost of the apparatus and the power for driving it is more than saved in a single season over the old method which involved waste through stock trampling their fodder under their feet. Further, by grinding and mixing the feed, any ration desired may be prepared.

One of our largest farming industries is that of stock "feeding," and in so far as the need for power is concerned, stock "raising" farms may be regarded in the same class, balanced rations for young stock being perhaps even more important than for "feeders."

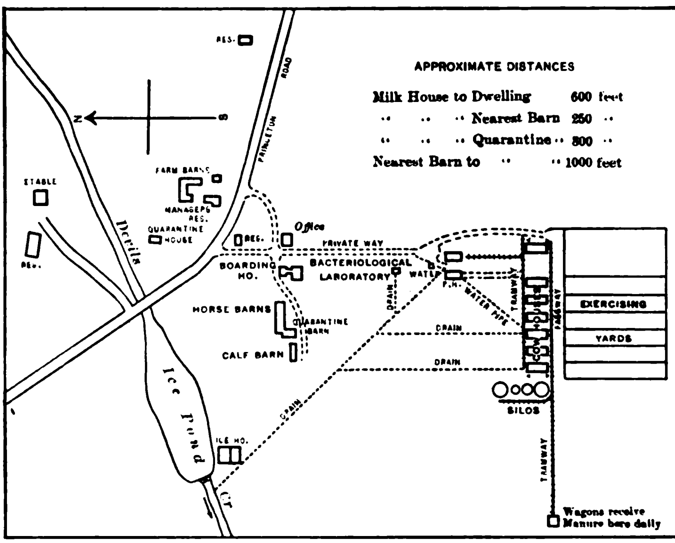


FIG. 12.—DIMENSION PLAN SHOWING POWER HOUSE AND ARRANGEMENT OF BUILDINGS ON DAIRY FARM AT PLAINSBORO, N. J.

On all such farms there is considerable demand for power, ranging in most cases from 25 to 50 h.p. and sometimes considerably more. Besides the power necessary on the individual farms, there are in all farming districts industries that convert the farm produce into finished products.

Electricity is gaining a foothold for both lighting and power in our better class of dairy farms. Its great cleanliness and safety for lighting leave little room for argument when new dairy buildings are being planned. And on account of its convenience as a form of power, it is frequently used with cream separators, churns, refrigerating machines, milk testers, also in the barn

or field work incidental to the preparation of feed and handling of crops.

Fig. 12 shows a large milk farm at Plainsboro, New Jersey, where electricity is used for lighting, clipping cows, operating a bottling machine, spinning on tinfoil caps or seals on bottles, cutting ensilage, running a saw mill, pumping water from a deep well, grinding feed and elevating it to storage bins.

The fact that this is a commercial plant turning out daily from 3500 to 4000 quarts of milk, where a high standard of quality is rigidly maintained, is evidence that there must be advantages in using electricity in such an installation.

The total acreage of the farm is nearly 1200, and at present about 70 per cent is under cultivation. Electricity is generated by steam power and distributed at 220 volts. The generating equipment, at present, consisting of one 25-kw. direct-connected unit, steam boiler, etc.

This is not a large generating plant, to be sure, but it insures cleanliness of lighting equipment and safety from fire risk in the barns, bunk houses and outbuildings. It also makes possible a convenient source of power in any part of the farms or outbuildings, which, of necessity, are widely distributed, and cost of generating the current, including interest and depreciation charges, is probably not over 4 cents per kilowatt-hour.

Scientific milk production is more and more coming into prominence and the necessity for perfect cleanliness, immediate cooling and keeping the milk at a low temperature, compels such dairy farmers to adopt devices that will be most helpful in obtaining these results.

Fig. 13 shows the bottling room at a milk dairy in Morristown, New Jersey, where the walls, ceilings and floors of all rooms in which the milk is handled are washed down daily, both morning and evening—the electric lighting fixtures being entirely water-tight.

"Dairying" and "stock raising" are usually followed where land needs up-building in fertility, and in either the silo is a necessity, cutting up succulent forage crops and storing them in the silo for later use being the accepted method of preparing the feed. To do this the farmer must have power, but a 10-h.p. electric motor with its capacity for momentary overload will do work that would stall a gasolene engine rated at 12 or 15 h.p. Hence, for silage cutting and elevating, a 10-h.p. electric motor is sufficient where a 20-h.p. gasolene engine would be recommended.

The farmer can easily recognize the advantage of the electric motor for this operation, and when once adopted, he soon wants to use the current for grinding feed, baling hay and other purposes.

On the dairy farm, however, electricity offers other opportunities, as it is the most convenient form of energy for operating an artificial refrigeration plant, the cream separator, churn and butter worker. The reason for this rests in the ease of control, making for economy. The current is used only while the apparatus driven is in operation and may be shut off when the work is done. No skill whatever is required to operate such equipments, it being necessary only to turn a switch.

Cream separators, while often turned by hand on small dairy farms, are more frequently driven mechanically where considerable cream is handled. Fig. 14 shows the use of the electric motor for separator driving where perfect cleanliness is a factor. Cream separators, except in the very large sizes, require not more than a 1/5-h.p. motor and they are in operation only for a comparatively short time. The operating cost, therefore, is practically negligible.

Figs. 15, 16 and 17 show a complete creamery outfit of excellent type, each piece of apparatus being driven by an individual motor. The power required for the various branches of creamery work is small, convenience and freedom from dust being the all-important factors.

In large dairies where hand milkers are difficult to obtain, the milking machine has a place and the records seem to show that these devices are favorably received in some of our western dairy sections at least. Those that the writer is familiar with which have been commercially used in this country consist principally of a vacuum pump, milk chamber with specially constructed admission valves, rubber connecting tubes and special type of cups which fit directly on the cow's teats, a convenient method of driving the vacuum pump being by the electric motor. These equipments are often called "electric milkers."

The only "electric" milker really deserving the name that has come to the writer's attention is shown in Fig. 18.

This device is so designed that an electric motor of about 1/12-h.p. forms an integral part of the apparatus that does the milking, the whole machine being suspended under the belly of the cow. Through a worm and gear the motor moves an aluminum rod forward and backward, which carries the pressure plates,

[BATES]

FIG. 11.—ACRES OF GARDEN TRUCK FORCED TO EARLY MATURITY BY IRRIGATION AND DRAINAGE.

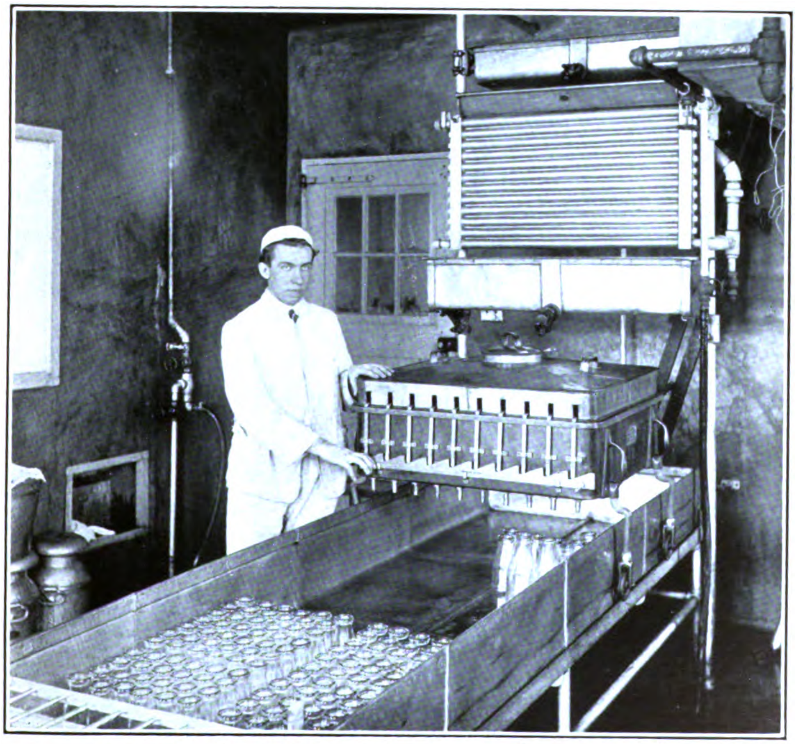
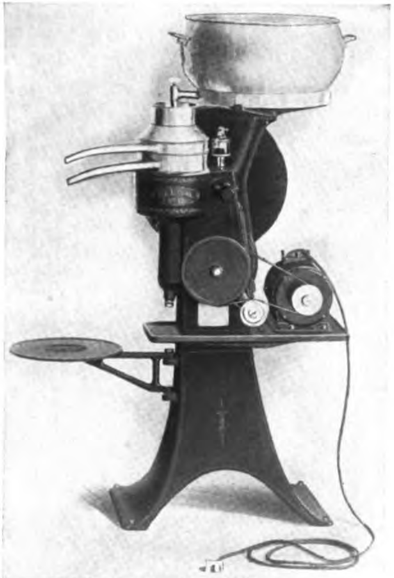
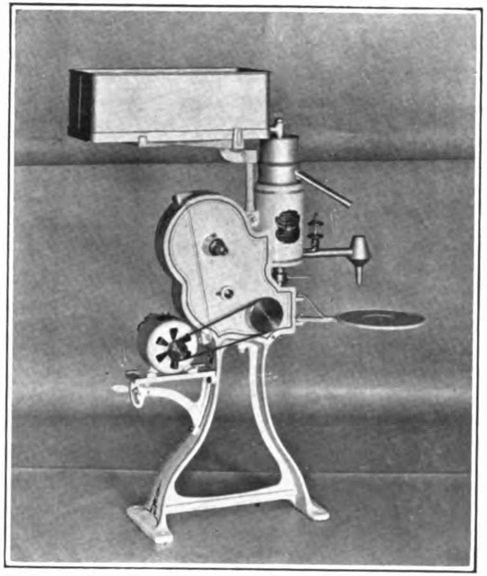


FIG. 13.—IN A DAIRY OR CREAMERY PLANT ELECTRIC FIXTURES MUST BE WATERTIGHT. [BATES]

In the bottling room the hose is used twice daily to " wash down " the entire interior, as in all the other buildings of this dairy farm at Morristown, New Jersey.



[BATES]
FIG. 14.—MOTOR-DRIVEN CREAM SEPARATOR.



[BATES]
FIG. 15.—CREAM SEPARATOR DRIVEN BY 1/5 - H.P. MOTOR.

[BATES]
FIG. 16.—BARREL CHURN WITH ELECTRIC MOTOR DIRECT-CONNECTED—$\frac{1}{4}$ TO $\frac{1}{3}$ H.P.

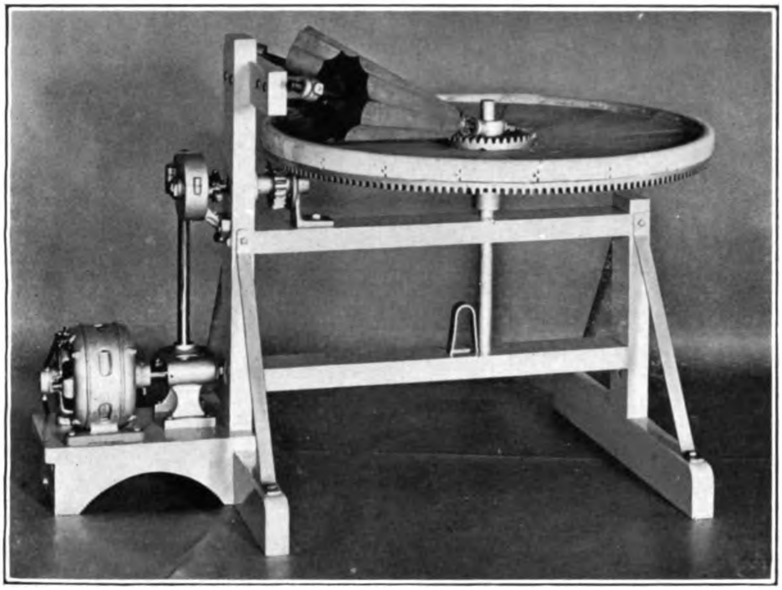
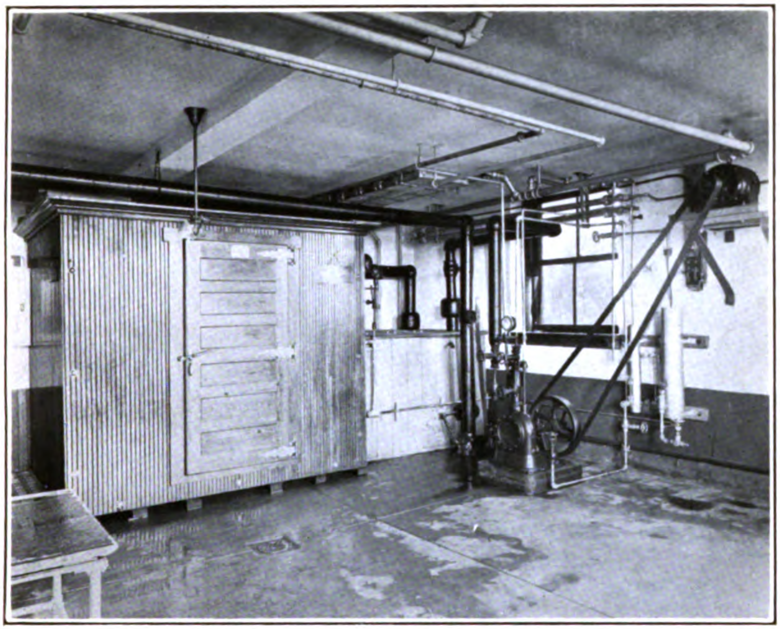


FIG. 17.—DIRECT-CONNECTED MOTOR-DRIVEN BUTTER WORKER. [BATES]

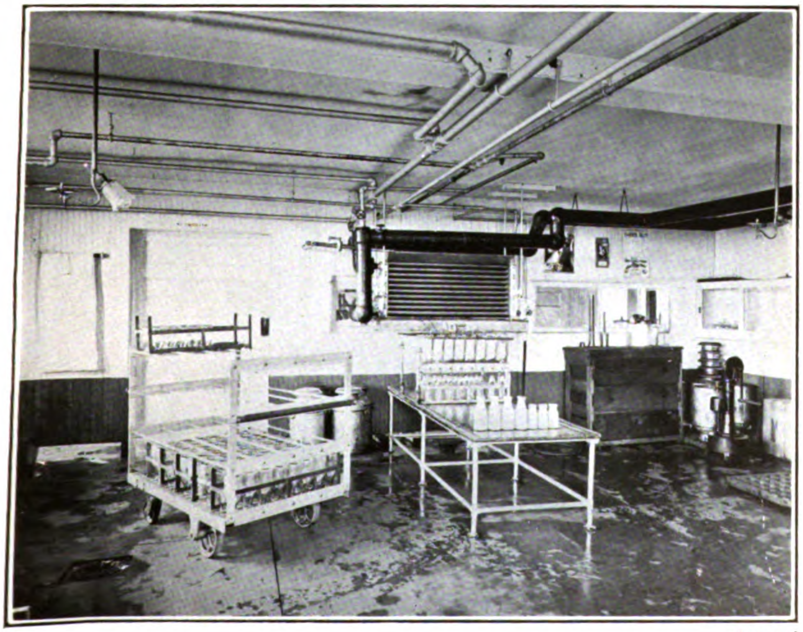
[BATES]

FIG. 18.—MECHANICAL MILKING MACHINE, ELECTRIC MOTOR AND MILK RECEPTACLE FORMING A PART OF EACH INDIVIDUAL EQUIPMENT.



[BATES]

FIG. 19.—$2\frac{1}{2}$-H.P. MOTOR BELTED TO AMMONIA COMPRESSOR USED FOR COOLING STORAGE REFRIGERATOR, MILK COOLER AND ICE-MAKING SET.
College Farm Dairy, New Brunswick, New Jersey.



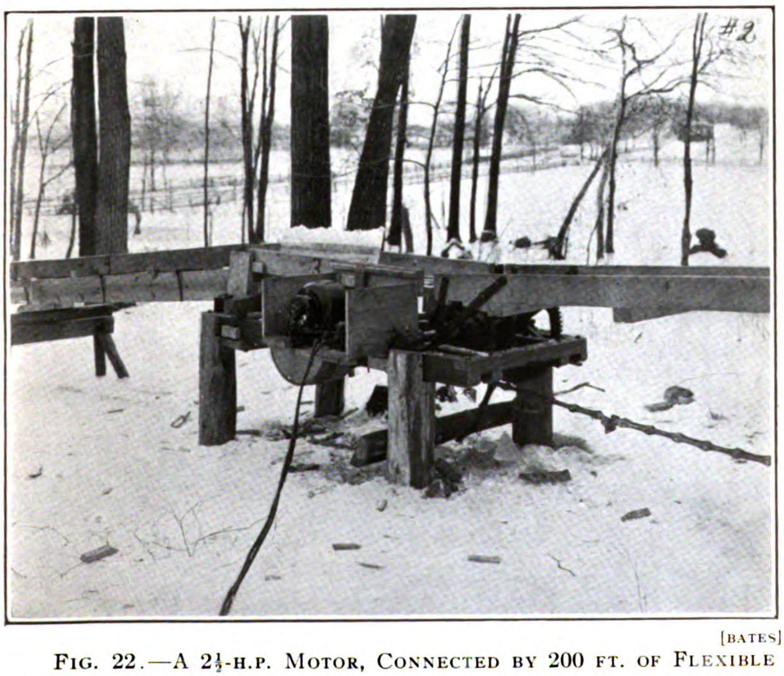
[BATES]

FIG. 20.—MILK COOLER AND AERATOR CONNECTED WITH INSULATED BRINE LINES RUNNING FROM BRINE TANK OF THE ELECTRICALLY-DRIVEN REFRIGERATING PLANT SHOWN IN FIG. 19.

[BATES]

FIG. 21.—HARVESTING ICE WITH TRAVELING CHAIN AND ELECTRIC POWER.

The "flights" are 33 ft. apart on the chain and there are ten of them, five on the "going side" covering a distance of 165 ft. The return trough for the chain is fastened up tight against the under side of the slide.



[BATES]

FIG. 22.—A 2½-H.P. MOTOR, CONNECTED BY 200 FT. OF FLEXIBLE CABLE WITH THE ELECTRICAL SUPPLY OF THE NEAREST BUILDING DRIVES THIS ICE HARVESTER.

and the teats, being held in a fixed position by a corresponding set of stationary plates, are thus squeezed as in hand milking.

It is an ingenious device, free from springs, tubes or other parts which might get out of order, and being of aluminum it is very light in weight. All of the details of design have been carefully developed, and as a machine milker, it is deserving of careful consideration.

As all dairymen know, refrigeration is an essential that they cannot do without. In many plants natural ice is still used, but the cost of harvesting, storing and handling ice is far greater than the operation of a power driven refrigerating machine.

Artificial refrigeration is more sanitary and far more convenient. Figs. 19 and 20 show a refrigerating equipment which was recently installed in the dairy department at the College Farm of the New Jersey State College of Agriculture, New Brunswick, N. J.

In this refrigerator is the usual brine tank through which the ammonia coils pass. The cooling of the brine and of the refrigerator entirely takes the place of ice. In other words, it is not a combination refrigerator, but is cooled by the ammonia pumped by an electric motor. The same pump and motor conducts ammonia through the inner compartment of the milk cooler and aerator shown in Fig. 20.

The motor is set running just before the milk is started to flowing over the cooler and aerator. The milk by passing over it is cooled and aerated, and run into the bottler just below. As soon as the milk has all passed over, the motor is turned off; thus the power used is a minimum.

Some dairies without this equipment, resort to pumping of ice-water through the cooler. This, of course, can be done with the electric motor or any other power and even by gravity. This last method is most common, but in warm weather it does not cool the milk sufficiently. The cooling which the electric ammonia system provides makes it possible to almost freeze the milk, and thus keep down the bacteria content by reducing the natural multiplication of these organisms.

Small refrigerators are beneficial on all farms for storage of eggs, dressed poultry and for preserving the freshness of flowers, fruit or garden truck that cannot be immediately sent to market. They are also useful for keeping meats and other perishable supplies for home consumption.

Figs. 21 and 22 show an ice carrying machine operated by

electricity on the farm of Dr. Schuyler S. Wheeler, who states: "The outfit was eminently practical and satisfactory in every way and enabled me to fill my house with about 200 tons of ice, using five men and no teams, in four days. Previously it has been the custom to employ four to six teams, four to five days in addition to these men." When the bridge was fully elevated, 2.5 h.p. was required, current for which was supplied from the private generating plant, ordinarily used for lighting and small power devices.

Individual uses for electric power on the farm seem to be almost without end. Fig. 23 shows the method of electric clipping employed in the dairy barns of a milk farm, and cow grooming is accomplished in similar manner. When milk of the highest quality is to be produced, the farmer must put his stock through a careful preparation for cleanliness, and it has been determined at several experiment stations, as well as in practical commercial dairies, that it pays to groom cows daily, owing to the greater production of milk thus obtained. In some cases this practise has resulted in an average increased output per cow of 15 per cent, which of course, even at a low value of milk, would pay for the electric current, man's time, etc. Figs. 25 and 26 illustrate other applications of electric power which are in successful use at this same farm. It can be said of this plant that everything that makes for quality and efficiency has been employed, but nothing that would suggest an over-capitalization of equipment.

In all farming one realizes that the time incidental to covering distance is one of the greatest handicaps to rapid production and the accomplishment of quick results. The force of this statement is hard to realize until one has actually observed the distance a farmer and his men will travel in a day by team or on foot in going to and from their work, the house or barn buildings. Perhaps the farmer will desire merely to speak to his assistants about their work, but, nevertheless, he must travel the intervening distance, as, generally, no other means of communication is available to him.

In the western farm life, this is not so frequently the case, as the telephone has been used there for several years, but in the East, strange as it may seem, the telephone is only rarely found in the farming home and in the fields.

Some time ago, one of the electrical manufacturing companies designed a water-tight telephone, Fig. 27, for mine, police and

railway service or other exposed use. The case is cast of heavy malleable iron, so shaped as to permit of attachment to a pole, post or side of building. The door closes against a rubber gasket, and when closed, the case is water-tight.

This form of local telephone station has been installed at some thirty different points on the farm of Mr. E. E. Ramsdell, Minot, Maine.

Mr. Ramsdell has introduced several electrical devices for saving labor on his form. The installation that has impressed me as being most worthy of especial mention, however, is his telephone equipment.

Fig. 28 shows the farm " central " and from any outlying point on the farm the owner or his men may talk to the farm headquarters, the nearby town, or to any place whatever, by " long distance " if necessary.

Another form of telephone equipment which should be very useful for field work on the larger farms is shown in Fig. 29, consisting of a portable magneto telephone, which may be carried as part of the field worker's outfit, and by means of a pole jack, which is also shown in the illustration, it is possible to signal to, or converse with any other part of the farm. Telephone installations of the kind just described may also include a separate water-tight loud ringing extension bell that may be heard at a considerable distance from the fixed signal point. Such apparatus, and in fact any electrical devices for farm use, should be substantial in construction and built to withstand weather conditions.

That electricity on the farm makes for great economy, not only through convenience, cleanliness and safety, but also in actual cost of operation, can be proved over and over again in the case of those installations where the service is properly installed and where apparatus of suitable type and size has been selected. For example, in one instance where the monthly output was considerable, the cost for electric power averaged from one-half to one and one-half mills per pound of butter made, the rate of charge for current being $2\frac{1}{2}$ cents per kilowatt hour.

Considering the cleanliness, minimum upkeep and labor required, this cost becomes negligible. And the difference in cost of using electric illumination, compared with the full costs incidental to burning kerosene, while somewhat dependent upon the relative rates of charge, is actually in favor of electricity, when chimneys, wicks and time of trimming are considered.

It may, therefore, be accepted as a fact that on the farm, as elsewhere, electricity for lighting and power results in lower cost, but to make this statement so that it cannot be disputed, I would add that where electric service cannot be obtained from a public supply on a basis that will insure reasonable rates, it is entirely within the privilege of the farmer or rural dweller to equip his property with a private electric generating plant that will give him light and power at moderate cost, and the operation of such a plant should not be difficult for anyone to understand.

The plant illustrated by Figs. 30, 31 and 32 perhaps embodies a maximum of simplicity and minimum of operating expense, for which reasons I refer to it as an equipment within the reach of anyone desiring the benefit of electricity with very moderate outlay. In this instance, a small dynamo (6 amperes, 35 volts at 450 rev. per min) is belted to the vertical shaft of a wind mill.

As the mill speed is not constant, an automatic cut-in is introduced in the electrical circuit between the dynamo and the storage battery, from which the lighting current is taken, the charging of this battery being the sole duty of the dynamo.

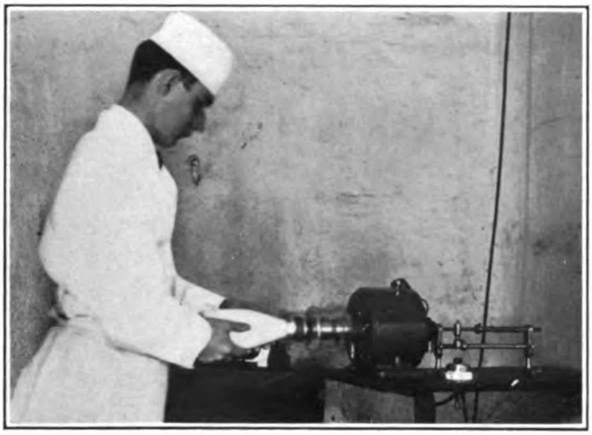
This plant, which is on the farm of J. F. Forrest, Poynette, Wisconsin, develops current for 24 15-watt, 25-volt tungsten lamps. Its whole cost was $250, exclusive of transportation, but including windmill, dynamo, storage battery, automatic cut-in, wire, porcelain insulators, sockets, switches and tungsten lamps. The owner did the complete wiring and arranging of the lights and switches. The two years of successful operation and the cleverness of the lighting scheme, which embodies several two-way and three-way switches for distant control of both exterior and interior lights, is certainly an indication that Mr. Forrest, who runs a farm of some hundred or more acres, has done for himself what many other farmers may also do by a little planning and some interesting labor.

To make this subject of electricity on the farm reasonably complete, there is shown Fig. 33 which illustrates a well-equipped generating plant where the dynamo is directly connected to a vertical type gasolene engine, the whole unit mounted together on one foundation. The storage battery is in the room adjoining, while the switchboard is built into a wall of the engine room.

In conclusion, I would state that the practicability and feasibility of utilizing electricity for both lighting and power on the farm has been demonstrated by many successful installations.

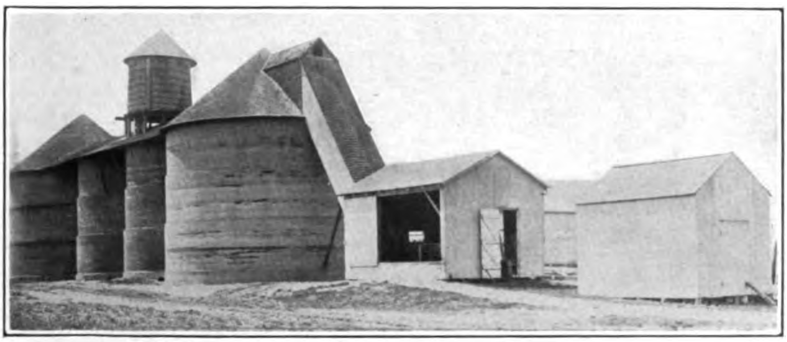
[BATES]

FIG. 23.—CATTLE AND HORSES MAY BE CLIPPED AND GROOMED BY ELECTRIC POWER.



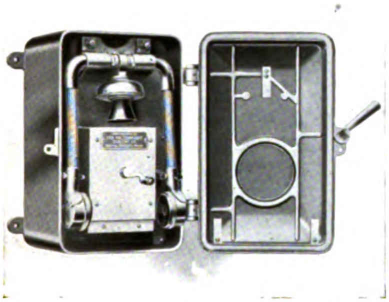
[BATES]

FIG. 24.—SPINNING ON TINFOIL CAPS ON BOTTLES OF HIGH QUALITY MILK. THESE CAPS CANNOT BE REMOVED AND THEN REPLACED.



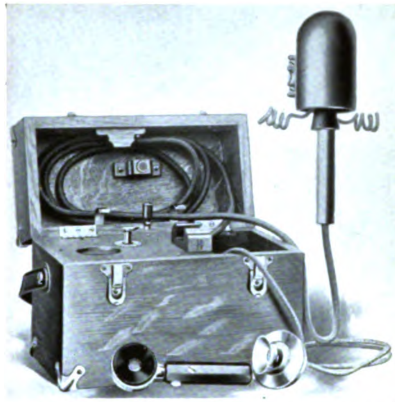
[BATES]

FIG. 25.—CUTTING ENSILAGE AND DELIVERING IT INTO THE SILO BY ELECTRIC POWER.



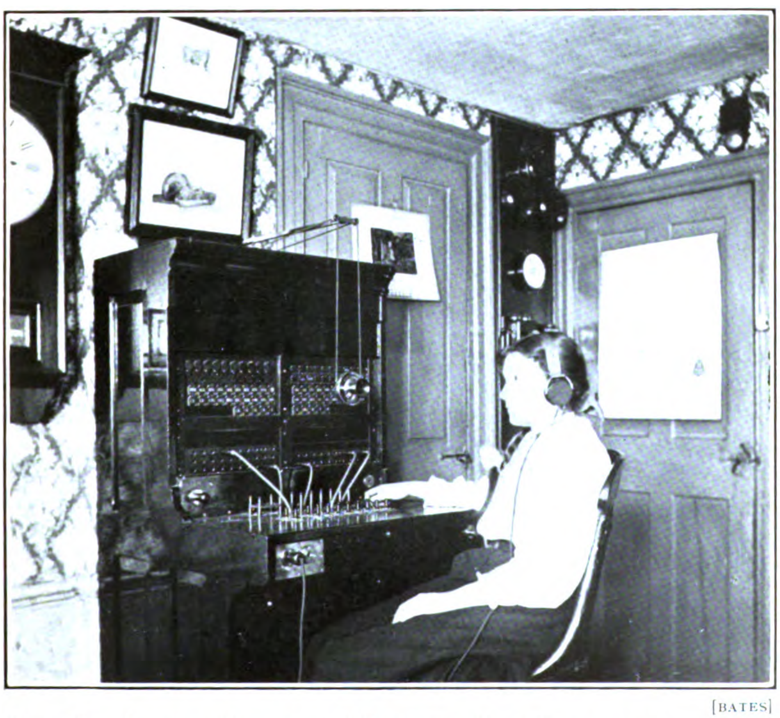
[BATES]

FIG. 26.—WATERTIGHT TELEPHONE STATION SUITABLE FOR USE ON THE FARM.



[BATES]

FIG. 28.—PORTABLE TELEPHONE STATION, INCLUDING TRANSMITTER, RECEIVER, MAGNETO AND CONNECTION TO LINE BY MEANS OF A "POLE JACK."



[BATES]

FIG. 27.—ON THE RAMSDELL "ELECTRIC FARM" AT MINOT, MAINE, THE FARMER'S DAUGHTER ACTS AS TELEPHONE CENTRAL.

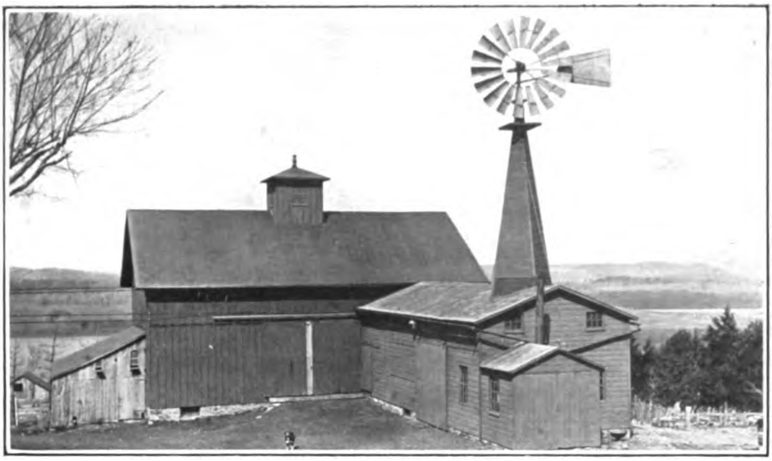


FIG. 29.—THIS WINDMILL DRIVES A DYNAMO WHICH FURNISHES CURRENT FOR TWENTY-FOUR TUNGSTEN LAMPS. [BATES]

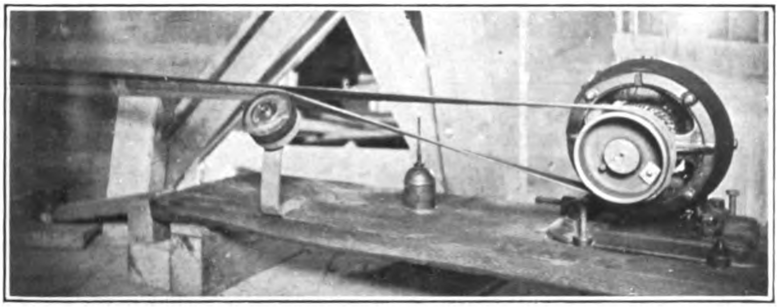


FIG. 30.—THE DYNAMO HAS A CAPACITY OF 0.21 KW. [BATES]

It is set on the second floor of the mill, and is driven by a quarter-turned belt from a pulley on the vertical shaft of the windpower.

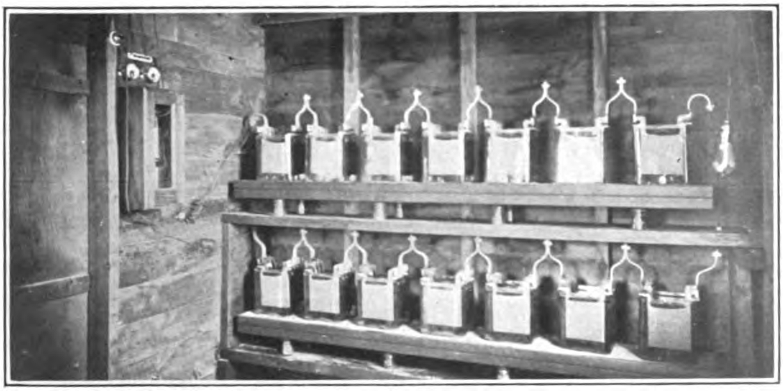


FIG. 31.—STORAGE BATTERY IN ADJOINING BARN, ACCUMULATES ENERGY GIVEN BY DYNAMO WHEN RUNNING, AND STORES IT FOR USE WHEN LIGHTS ARE TURNED ON. [BATES]

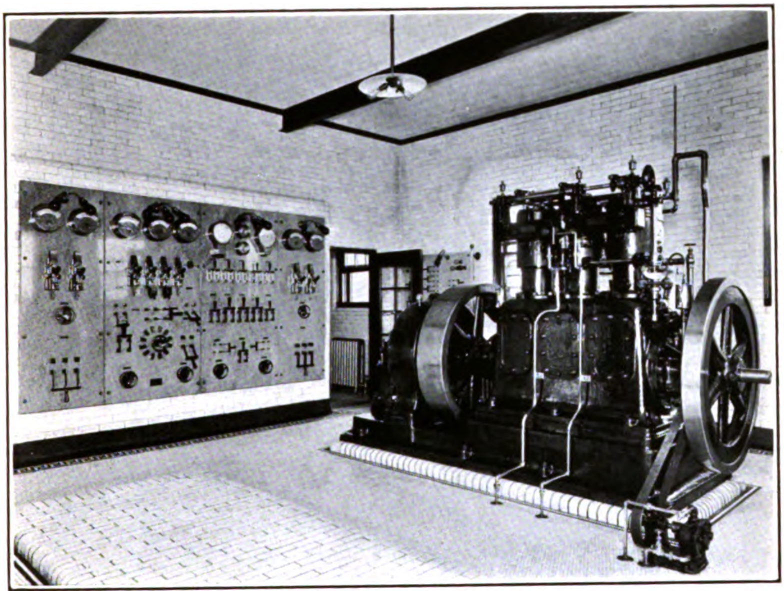


FIG. 32.—A HIGH-POWERED EQUIPMENT FOR A LARGE FARM. [BATES]

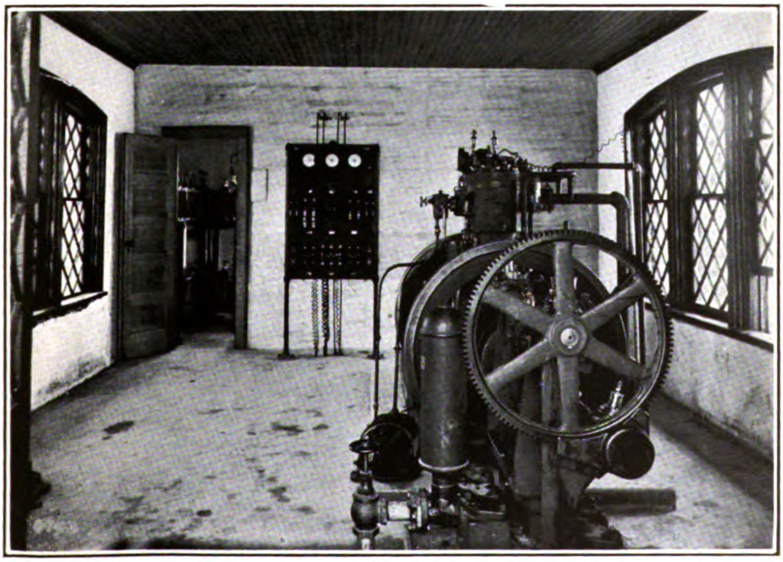


FIG. 33.—AN IDEAL PUMPING PLANT FOR FIRE PROTECTION. [BATES]

In some agricultural sections, central station operators are stimulating a general use of electricity in rural districts by following a far-sighted policy as to extension of service lines and rates for current.

Should one or more isolated farmers find it impracticable to obtain central station service, there is open the opportunity of establishing a cooperative generating station, utilizing water-power, producer gas, steam, gasolene or fuel oil equipments, depending upon the conditions obtaining.

In conjunction with such cooperative electric generating stations, there could be operated community laundries, creameries, canneries, grist mills or other industries suggested by local needs.

Where neither public service nor cooperative plants are feasible, a farmer may, at a cost of approximately $250, install a private electric lighting plant, large enough for two dozen lights, and from this as a probable minimum, he may install an isolated plant at additional outlay that will provide current for as many lamps and as much power as he may desire.

The use of electricity on the farm makes for greater safety from fire risk, and for this reason especially, its use should be encouraged for lighting, heating and power.

And, finally, as our future land improvement in the East, as well as the South, will involve drainage and irrigation, we may expect to see here, as in the West, electricity taking a leading place in agricultural development. It should be remembered, too, that electric energy is greatly cheaper than man or horse power, and that nowhere else are man and horse labor wasted through periods of inactivity to an extent to be compared with the labor waste on the farm. Now, when it seems impossible to secure men on the farm, the turn of a switch brings electric energy, begetting production and wealth.

A communication presented at the 29th Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June 24-28, 1912.

THE MYRAWATT

BY H. G. STOTT AND HAYLETT O'NEILL

The object of this communication is to introduce a new unit of power which, if adopted, will afford a basis of comparison of all converters of energy, thermal and mechanical; and also will be international in its character, as it is merely a new multiple of the watt.

In American and European practise, at the present time, there are in use many empirical units, the use of any one of which is restricted to a distinct territory. A few of the more important ones are, horse power, boiler horse power, kilowatt, cheval à vapeur, pferde-kraft and poncelet. Obviously an engineer in attempting to compare data from a foreign country, is compelled to face a confusion of terms, which usually can be made intelligible only by laborious calculations.

Again, in the United States there are in vogue such units as boiler horse power and horse power, which, while similar in sound, have no logical connection; and one has yet to find where the "horse" comes in.

With the rapid development in electrical measuring instruments, and, until recently, a corresponding lack of development in steam-flow measuring instruments, the term kilowatt has become more and more used as the one unit of power output.

The term became a necessity with the growing favor of steam turbines, and all direct-connected units where it is impossible to measure accurately the mechanical and the electrical power separately.

To form a connection between the boiler or producer output, the engine and generator output, the term "myrawatt"—

derived from the Greek "myria," meaning ten thousand, and the term watt—is proposed.

For the purpose of standardization, the British thermal unit, 1/180 of the heat required to raise one pound of water from 32 deg. fahr. to 212 deg. fahr. and the equivalent evaporation from and at 212 deg. fahr. (970.4 B.t.u.) is used (Marks and Davis).

From this, the following equivalents are obtained:

1 foot-pound	=	0.001286	B.t.u.
1 horse power	=	2,547	B.t.u. per hr.
1 cheval à vapeur	=	2,510	B.t.u. per hr.
1 pferde-kraft	=	2,510	B.t.u. per hr.
1 poncelet	=	3,350	B.t.u. per hr.
1 kilowatt	=	3,415	B.t.u. per hr.
1 boiler horse power	=	33,479	B.t.u. per hr.
1 myrawatt	=	34,150	B.t.u. per hr.

The last two are practically the same, differing by only two per cent. The usual practise is to rate water-tube boilers on the basis of one boiler horse power per 10 square feet of heating surface.

With modern plants, notably those in marine service, operating from two to five times this rating, the ordinary method of determining nominal boiler capacity could be stretched 2 per cent without materially affecting the present rating: *i.e.*, the boiler might be rated at 34,150 B.t.u. per hour for each 10 square feet of heating surface, instead of at 33,479 B.t.u. per hour for each 10 square feet of heating surface.

The myrawatt as a unit of boiler or producer output, and correspondingly a unit of input to all kinds of dynamical machinery, is fixed in value by the watt, and by its very sound gives a clue to its meaning.

To compare efficiencies of direct-connected units and eliminate the various factors of quality of steam, pressure and vacuum, the term "B.t.u. per kilowatt-hour" has been used. If we used the term myrawatt,

$$\text{per cent overall efficiency} = \frac{10 \times \text{kilowatts output}}{\text{myrawatts input}}.$$

Also, with the thermal efficiency of the engine known, the heating surface in the boiler room is determined (assuming the 10

square feet rule), thus, two kilowatts per myrawatt input to an engine is equivalent to 20 per cent thermal efficiency of the engine and the heating surface in the boiler room equals kilowatts engine output $\times$ 10/2.

Obtaining an exact figure of the same with the boiler horse power unit involves a tedious operation.

The efficiency of internal combustion engine-driven units of all cycles, such as Diesel, Brayton, Otto, etc., is determined by rating the heating value of the fuel in myrowatts; thus

$$\text{per cent efficiency} = 10 \times \frac{\text{kilowatts output}}{\text{myrawatts input}}$$

With hydraulic machinery, again rating the water power input to the wheels in myrawatts:

$$\text{per cent efficiency} = 10 \times \frac{\text{kilowatts output}}{\text{myrawatts input}}.$$

Thus, in the term myrawatt lies a simple, logical and universal means of comparing outputs and inputs of all classes of energy converters, the meaning of which will be clear to all engineers wherever a piece of electrical machinery is to be found.

Comparisons in Efficiencies and Rates of Output With Various Types of Energy Converters, in Terms of the Myrawatt

1. Boiler output:

Nominal rating = 600 boiler h.p.

Total draft head inches water gauge	Boiler h.p.	Myrawatts
0.589	817	800
1.170	1174	1151
1.730	1375	1348

2. 5000-kw. engine:

Kw. output	Lb. steam / kw-hr.	B. t. u. / kw-hr.	Kw. output / Mw. input	Per cent thermal efficiency overall
3100	18.2	21,500	1.59	15.9
4977	17.2	20,160	1.70	17
6772	18.5	21,600	1.58	15.8

3. 5500 kw. high pressure turbine:

Kw. output	Lb. steam / Kw-hr.	B. t. u. / Kw-hr.	Kw. output / Mw. input	Per cent thermal efficiency overall
2283	20.16	23,100	1.48	14.8
5350	16.86	19,160	1.78	17.8
8183	16.39	18,450	1.85	18.5

4. 15,000-kw. engine—low-pressure turbine.

Kw. output	Lb. steam / Kw-hr.	B. t. u. / Kw-hr.	Kw. output / Mw. input	Per cent thermal efficiency overall
8,347	13.34	15,740	2.17	21.7
11,240	13.19	15,660	2.18	21.8
16,172	15.07	17,500	1.95	19.5

5. 56-in. low head water-turbine:

Brake h.p.	Brake kw.	Kw. output / Mw. input	Conversion eff. per cent overall
294	219	7.83	78.3
283	211	8.41	84.1

6. Steam plant efficiency:

Lb. coal per kw-hr.	=	2
B. t. u. per lb. coal	=	14,250
B.t.u per kw-hr.	=	28,500
Kilowatts per myrawatt input to boilers	=	1.2
Plant efficiency	=	12 per cent.

7. Gas power plant efficiency:

Kw. output	Cu. ft. gas / Kw-hr.	B. t. u. / Kw-hr.	Kw. output / Mw. input.	Per cent thermal efficiency overall
5200	145	14,220	2.4	24

Discussion on "A Method of Studying Power Costs with Reference to the Load Curve and Overload Economies." (Rhodes) New York, February 9, 1912. (See Proceedings for February, 1912.)

(Subject to final revision for the Transactions.)

H. G. Stott: I think you will all agree with me that if Mr. Rhodes had not been a young man, he would not have tackled such a subject as this. In going through college we used to think if we had to tackle an equation with three variables in it, we were doing just about enough. In the problem before us there are eighteen variables and if he has arrived at a conclusion we are to be congratulated, and he much more so.

I will run over one or two of the items which enter into cost of power. The simplest part of it probably is the part related to investment, of which 12 per cent per annum must be charged against operation. Investment in a power plant is made up of three principal items: Real estate, buildings, and boilers and machinery. As an instance of the complication of this subject, I point to the item of real estate. In the average city, in the United States at all events, real estate, instead of depreciating, is appreciating; in some cities, possibly due to some local conditions, there is an actual depreciation, so here we have a positive or negative variation.

The depreciation in the case of the building is very small, as an average, not more than one or two per cent at the most. Boilers and machinery, if properly kept up, have a very small rate of depreciation, but they have an enormously high rate of obsolescence, and that is determined by the ability and the energy of our inventors and manufacturers who are developing new apparatus. We do not know to-day whether or not there will be an announcement made to-morrow of improvement in machinery which will put the steam turbine out of business. Then the depreciation of the turbine will perhaps be at the rate of 25 per cent per annum, so that the number of variables entering into this, the simplest of all the unknown quantities, is appalling. The steam engine had just about reached its zenith in progress when the turbine appeared, and I think it is the opinion of engineers that the average life of a well built steam engine, ought to be twenty years. Now, at this time, steam engines which have been operated for over six years are considered obsolete.

Now, coming to operation, it is even more complex. We find in the case of coal, the assumption is that the value of coal is proportional to the heat units contained in the coal. That is a good generalization, but it is not strictly true. There is a modification required in that statement, because the more ash you get in the coal, the less possible it is to utilize all the heat units in it, so that there is a function in which ash enters to reduce the value of the heat unit.

As to the labor, that is an item which is variable also in its efficiency, but it is practically in the hands of the management

of the plant to see that high efficiency is obtained, so that variable is not so difficult to calculate. In the case of water, that is usually not more than 10 per cent of the value of the coal, and its cost is entirely dependent upon the fact of whether we use the water over again in the boilers, or whether we do not,—whether we prefer to sacrifice it for other considerations.

Supplies are a small item, and usually proportional to the rate at which the plant is run. In maintenance, under the heading of "labor," we have an item which is proportional, not so much to the rate at which the plant is run, as to the amount to which it is overloaded. Material will also vary, partially proportional to the kilowatt output, but more in proportion to the overload.

In going over this paper, in regard to which I desire to express my admiration, it seems to me that there is one thing which we should ask of our Standardization Committee, and that is to define what is "rating." The value of the paper depends to a great extent on what is meant by "rating," and I think it would be a very good thing if we could get the Standardization Committee to hold a conference on that subject. Rating, some time ago, in the days of the steam engine, used to be considered the point of maximum efficiency of the unit, in other words, the point of lowest steam consumption. To-day rating is usually based upon the maximum safe load with the turbine unit, and has nothing whatever to do with the point of highest economy. This leaves a tremendous margin between these two limits, and one which renders it almost impossible for us to interpret just what "overload" means. As a suggestion, I think if we go back to the old system, in which the engine was rated by calling the "full load" of the machine, the point at which it operates most efficiently, and calling everything beyond that point "overload capacity," we will have something which will be a fixed and exact definition of the word "rating."

On the first page of the paper Mr. Rhodes makes the following statement: "By far the largest and most important item entering into the cost of power is that of fuel." Of course, from Mr. Rhodes' point of view, that applies strictly to the operating and maintenance charges, but, as a matter of fact, the most important item, with low load factor, is unquestionably the fixed charges, so that this paragraph or sentence is, in a sense, contrary to the whole sense of the paper—the principal object of Mr. Rhodes' paper, as I conceive it, being to point out the necessity of keeping down the fixed charges, and how relatively unimportant the maintenance and operating charges are on overload.

I think, perhaps, the whole paper might be summed up by saying that we have here a very earnest attempt to place upon a rational basis what has heretofore been purely an empirical study of the subject, and the actual value of the paper will have to be determined, I think, after it has been applied in a great many instances to see whether the assumptions, such as those

given at the beginning of the section on "Relation of Load Factor to Operating Power Costs," are justified and can be carried out fully.

In nearly every case in the progress and development of the electrical art we have had first of all an empirical statement or formulas to express, as closely as possible, results which have been deduced from experiment and actual experience. Later on some one has analyzed these results, and found that some purely rational formulas or statement could be made which covered them more exactly, and then, after that is discovered, we find why the empirical statement is wrong, and this paper, I think, should be looked upon with a great deal of confidence as the first step in reducing what has been more or less an empirical state of the art to a rational one.

Hartley Le H. Smith: Whenever anyone attempts to use mathematics on subjects which ordinarily escape it I am always interested and so I regard the paper of the evening as significant and important. It seems to me, however, that the mathematical methods used and the justification for them made in the text are in some respects awkward and inadequate. The author at considerable length discusses why it seems justifiable to assume that the input of steam apparatus is related mathematically to the output of the apparatus by an equation involving the square of the output—in other words that it is justifiable to assume that the input varies directly with the load and also in addition with the square of the load—and he uses as analogies the variations of the various losses of electrical apparatus whereby the input of such apparatus is related to the output, and while he takes pains to state that the variations in the losses of steam apparatus are not nearly so clearly defined nor so easily measured, there are certain courses of reasoning which lead up to the conclusion that to no small extent a term involving the square of the output is a reasonable and proper one in attempting to relate mathematically the input of steam apparatus to its output. With some of the reasoning by which this is done I decidedly disagree, but aside from this I think that no attempt to put the presence of a term involving the square of the output of steam apparatus on a rational basis is necessary; it has its complete justification upon an empirical basis. This basis is as follows: Any expression relating mathematically the input of apparatus to its output will give by the simplest sort of transformation the efficiency of the apparatus, that is the output divided by the input. Now the graphical representation of the efficiencies of most sorts of power plant apparatus gives lines of very well known shape—they are low on light loads and rise, almost always at a decreasing rate, until the high efficiency at the most economical load is attained, and then fall off somewhat slowly and usually at an increasing rate as higher and higher overloads are reached. Now obviously a general mathematical expression relating the input of apparatus to its output must be chosen of

such form that when the simple transformation is made which gives the efficiency—the ratio of output to input—the shape of its locus or graph will be such as to conform to the facts, that is, the actual shape of the efficiency line of the apparatus in question. Now this fundamental consideration marks off very sharply the permissible choice of forms which the general mathematical expression may have. For instance, to illustrate very specifically, the equation representing the input of a steam turbine in terms of its output in the load range which can be handled by the ordinary governing mechanism, the range of load capable of being handled by the primary valve alone on Parsons type turbines, is a marvelously simple one, a straight line. Scarcely any other apparatus in a modern power plant has such a simple relation existing between its output and its input. A steam engine working with a throttling governor has such a relation, and it was the pointing out of this relation by Willans which established the expression " Willans' line law," and it is a fact of exceeding interest that steam turbines obey this simple law within the range which I have mentioned. Now a most important further fact is that transforming a straight line expression between input and output by the very simple manipulation which gives the efficiency, results in an equation which will not show a point of maximum efficiency beyond which the efficiency declines. Instead of this the efficiency rises continually, although at a decreasing rate, and this of course actually characterizes a steam turbine, the most efficient load being always that which it will carry just before the opening of the secondary valve. Now the efficiency lines of other apparatus in a power plant except steam turbines *do* rise to points of maximum efficiency and then fall off to lower efficiency values as overloads increase. Therefore, necessarily, straight lines cannot be used to represent the mathematical relations between output and input of the general apparatus in a power plant. Now so long as the general polynomial form of mathematical expression is adhered to it follows that a term in x^2 (x representing the output) ***must*** be used and no other justification of any nature whatsoever is necessary for it. Thus if y represents the input and x represents the output of any power plant apparatus the straight line Willans' law expression is

$$y = A + Bx$$

and the expression giving the efficiency of a machine obeying Willans' law is

$$\frac{x}{y} = \frac{x}{A + Bx}$$

Now this expression, irrespective of the values of A and B, will not rise to a maximum and then fall off—it approaches an asymptote which it would only reach at infinite load. In actual practice with a steam turbine its nearest approach to this asymptote

is at the load just previous to the opening of the secondary valve, which changes entirely the efficiency characteristic of the machine and makes it a discontinuous function. An efficiency characteristic of apparatus working with a straight line relation between input and output is illustrated in Fig. 2, the straight line itself being shown in Fig. 1. The height of the asymptote representing the maximum efficiency is $\frac{1}{B}$, but, as stated before, this efficiency can never be reached. On the other hand, when a term in x^2 is added in the equation between input and output, it becomes $y = A + Bx + Cx^2$ and the efficiency is obviously $\frac{x}{y} = \frac{x}{A + Bx + Cx^2}$. Very simple differential calculus serves

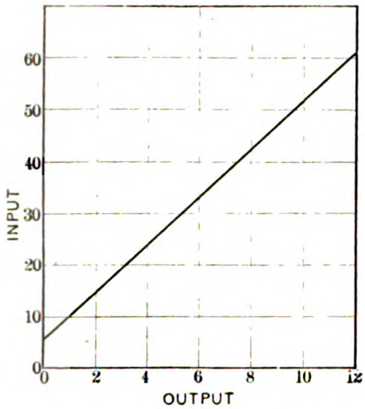


FIG. 1.

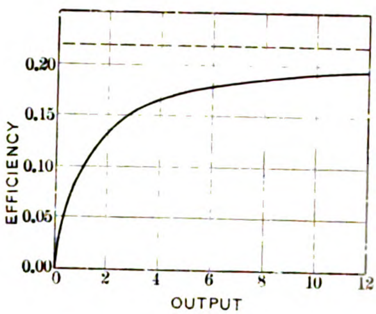


FIG. 2.

to show that this does reach a maximum at the load $x = \sqrt{\frac{A}{C}}$, the efficiency having the value $\frac{1}{B + 2\sqrt{AC}}$. Such an efficiency characteristic is shown in Fig. 4, the line representing the input in terms of output involving this efficiency characteristic being shown in Fig. 3. The efficiency characteristic shown in Fig. 4 is the normal efficiency characteristic of power plant apparatus—engines with shaft governors or with corliss gear, boilers, centrifugal pumps, and so forth—the steam turbine operating within the range of its main valve constituting the sole exception Obviously the use of a term in x^2 in relating input to output of apparatus needs no other justification than this: it is good and sufficient.

After this a matter most open to criticism comes up. The author of the paper, after writing down polynomials up to the square of the load in relating the input of prime movers to the output and also in relating the input of boilers to their output, then proceeds to combine them. The output of the boilers is of course the input to the prime movers. Although he does not say so he makes a straight substitution and multiplies through algebraically, obtaining of course a polynomial extending up to the fourth power of the output of the prime movers, that is, the load. Now this I say is entirely illegitimate. It is perfectly good mathematics but very poor engineering. Such a polynomial represents no engineering reality whatever. No power plant apparatus individually or in combination has either an efficiency characteristic or input characteristic involving the fourth power

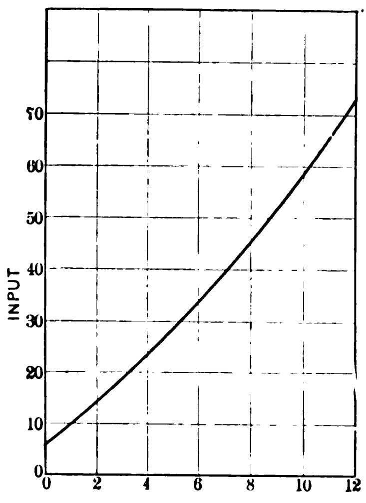


Fig. 3.

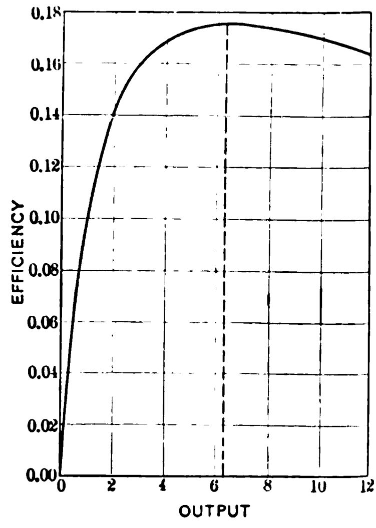


Fig. 4.

of the load within the meaning of engineering reality. That is, the coefficient of the fourth power could never be determined from the actual facts of the characteristic itself. Steinmetz warns us against this sort of thing in his book "Engineering Mathematics" where, on page 213, after discussing the potential series (the sort of mathematical expression we are dealing with), he says: "Usually, however, such representation is irrational, and therefore meaningless and useless." Power plant data are proverbially widely scattering when considered for the establishment of any mathematical relations and therefore it may be said unequivocally that for power plant study a potential series extending to the fourth power is always irrational, meaningless and useless.

Aside from this technical criticism there is room for criticism of the paper at this point on broader engineering grounds. It seems entirely irrational to combine the efficiency relations of prime movers and steam boilers. Power plants operated for maximum economy are not operated that way and every unlettered man concerned with power plant economics knows that the boiler room must be operated for its best economy and that the engine room or turbine room must be operated for its best economy, the best economy of the individual prime movers in it, and that only when the *discontinuous* elements of a power plant are each operated at best efficiency will the efficiency of the plant be at its best. Of course, to the designer and not the operator the question of the total rated capacity of the steam generating plant in terms of the total output capacity of the prime movers is determinable, with fixed charges of all apparatus taken into consideration, by a combined consideration of input and output of the total plant, and this is not left unregarded in the paper, but I think the distinction is not sufficiently emphasized and maintained.

Aside from the above objections, I think the nomenclature for injecting the load factor into the equations, and the resulting equations, are awkward and needlessly obscure; that is, I think they would well stand clarification.

P. M. Lincoln: The most startling thing I find in Mr. Rhodes' paper is the nonchalant way in which he sets aside as a mere manufacturing detail the proposition of obtaining electrical apparatus capable of assuming the very high overload which he suggests. Those who are familiar with the design of electrical apparatus and particularly the prime movers which are used to drive it, know that it is practically impossible to design electrical apparatus so as to assume the two or three times full load rating which he suggests in his paper. Not only are these high overloads impossible on account of the limitations of the electrical apparatus, but they come from the limitations of the prime movers as well. The prime movers which are being installed at the present time are often rated in what is now referred to as a "maximum rating." I am not altogether in sympathy with this method of rating, but it is here and it is a thing to be reckoned with. However, although not in sympathy with the idea of the so-called maximum rating, on the other hand I am not willing to follow Mr. Rhodes as far as he seems to have gone in his paper, namely, to the extent of assuming that as high as two times full load, or even more, can be obtained from electrical apparatus driven by prime movers. We know how impossible this is even though we are willing to make the utmost sacrifice in efficiency at very high overload points.

Reverting again to methods of rating, which I have just spoken of, in former days we had ratings which are now called normal ratings, in order to distinguish them from the term "maximum ratings" which has come into use during the last

few years. The normal rating was usually that rating which would cause an elevation in temperature of the electrical apparatus of 35 or 40 deg. cent. above surrounding atmosphere. The maximum rating which has crept in during the past few years is usually taken as that rating which will raise the electrical apparatus to a temperature of about 50 deg. cent. above surrounding atmosphere. The relation between normal rating and maximum rating is not definitely fixed, but there is a difference of approximately 25 or 30 per cent. In other words, a machine which has a normal rating of 100, will have a maximum rating of approximately 125. This new method of rating, of course, requires us to change entirely our ideas when we come to speak of the costs or outputs of electrical stations, particularly when they are put in terms of cost per kilowatt. It practically makes another value of kilowatt. On account of this changing the value of the kilowatt and the confusion that is bound to come from it, I am not in sympathy with the proposition to establish the so-called " maximum rating."

C. O. Mailloux: I do not think the discussion has done justice to this paper, which has far more meaning and importance, I think, than many of us realize on merely glancing at it. I look upon this paper as being just as much epoch-making in its way, as was the classical paper of Mr. Stott, presented before the Institute several years ago, on the question of boiler economy and cost of power.

We are probably indebted to Mr. Stott, more than anybody else, for this paper; and it is a tribute to his standing as an engineer, just as it is a great credit to the author. At the same time, I think we can throw some bouquets at ourselves as an electrical body for having been the means of bringing out a paper like this. This is, in my opinion, one more case where we get in ahead of the older sister engineering societies.

Taking a broad view of the question of precision in engineering work, we see, without going back very far, that the electrical engineer has played a great part and has done more than his share in impressing upon the public the importance of clear thinking, accurate planning, and careful measurement. I think it is safe to say that if it were not for the fact that electrical engineering as an art has made so much progress, there would be as much blundering and empirical work in the use of coal and in the generation of power generally as there was in the good old days of the so-called age of steam, fifty years ago, which preceded the electrical age, or before electricity or electrical engineering came on the scene. It was the electrical engineer who first learned to measure power systematically and correctly. It was he who first made general use of instruments of precision inside a power station; and, after he had made a great success with his methods of precision-measurement in his own department, in the dynamo room, he found it desirable to go into the boiler room and repeat the same success there, in doing away

with the old, crude, rule-of-thumb methods. Mr. Stott himself was one of the first men who preached that doctrine after having practised it himself, with very gratifying results; and the men who are following his example are precisely the ones who are in the front rank as experts in power station management and economy. Incidentally, it is gratifying to note that the best men here have been recruited mostly, if not wholly, from the electrical branch of the engineering profession.

This paper represents what might be called an advance step in that program of progress which was inaugurated by Mr. Stott and men of his ability and experience in dealing with the problems of economic power-generation. These men understand and appreciate fully the far-reaching importance of methods of correlating and coordinating facts, because it is by means of such methods that they can hope to bring to light the relations of certain sets of facts to other sets of facts, and by doing so, learn the way to better and more satisfactory practical results. Here we have an interesting attempt to go a step further than has been attempted hitherto in that direction. The author has endeavored to assort the different factors which enter into the general problem of economy in the power plant; and, after having assorted them, after having given them names, after having found their numerical values, we have an effort here, and a most intelligent one, to correlate them, to bring them together in such a way that we can begin to think about them concretely and begin to assimilate the ideas which they represent, and see them in perspective, as it were, and thus understand and appreciate better than we could before their relative value and importance.

I think it would be unfortunate if the discussion were to close without removing the bad impression left by the speaker who found so much fault with the mathematics in this paper. I want to say that the paper impressed me particularly because it was *not* a mathematical paper,—because, in fact, it was merely a very simple way of placing before the reader in the simple symbolic language of algebra the interesting facts which the author has worked out, the coefficients which he has boiled down or deduced from the curves employed in the graphical method used by him.

I regret that there is not time to go into a detailed discussion of the mathematics placed on the board by the previous speaker, so as to show their fallacy, or their irrelevancy, so far as their applicability to this case is concerned. Perhaps a great deal of the apprehension about the asserted mathematical character of this paper comes from the rather formidable appearance of the integral equations for the total energy, but it does not require much knowledge of mathematics to see that, really, they are very innocent things, not at all as formidable as they look. These integral expressions, in reality, present no difficulty whatever. They are only what are usually termed " indicated "

solutions. It does not need extended mathematical study to know perfectly well that these solutions cannot always be obtained analytically, in the manner which the integral symbolic expressions on the left hand side indicate, but that they must often be obtained graphically, or in some other like manner.

The indicator diagram of the steam engine is a well known instance. The area, or else the mean effective pressure, in the case of a steam indicator diagram, just exactly as the area of the electrical load diagram or else the average load of a power station, can be represented and expressed correctly in mathematical symbols only by an integral expression precisely similar to those given by the author. Yet the valuation of such integral expressions by purely analytical methods would be beyond the powers of the ablest mathematicians. Fortunately, there are practical and relatively simple means of evaluating such integrals. In the case of the indicator diagram, it is done, as we all know, by a planimeter. In the case of the electric load diagram, it can also be done by a planimeter, if the load curve has been obtained by means of a curve-tracing instrument, or it can also be done without that, by simply taking the readings of a watt-hour meter, which is a very perfect integrating mechanism. You will note that in at least the first two of the integral equations for the total energy, the solution can be very easily obtained by the ordinary processes of graphical integration, such as by the use of planimeters or integraphs, or else by integrating watt-meters or ampere-meters, according to the case. The others may be obtained readily enough by methods of transformation of curves and then by integration by means of mechanical or graphical methods. Hence, we are not at all being confronted by an elaborate attempt at mathematical befogging. On the contrary, we have merely a very simple, and I think a very intelligent and convenient way, of noting in a sort of shorthand the results which the author has obtained.

Now, so far as the criticism of the higher powers is concerned, I want to say that I consider this one of the interesting and specially original and valuable features of this paper. I dare say that even in electricity, where we know that the energy expended in the circuit is proportional to the square of the current, very few engineers realize that it is of the highest interest for us to get some factor which is proportional to the root mean square of the electrical load diagram, because the loss which takes place in the feeders is not proportional to the main current at all, but proportional to the root mean square of the load-current during a stated interval of time. There are losses due to temperature, to radiation in piping, and what not, occurring in a boiler plant, which may well be conceived to be not only proportional to the second, or third, but may, perhaps, be proportional to still higher powers. The author has found a most intelligent way, I think, of presenting to the reader a summation of the knowledge which he has collated and gathered.

We know perfectly well that any mathematical expression which complies with certain mathematical requirements, that is, provided it is single-valued, and has certain other mathematical earmarks, such as admitting of a derivative, can be expressed in the form of a series of ascending powers of the variable. The author has taken advantage of this property very satisfactorily, and he has deduced an algebraic expression, containing a certain series of terms, (like a "Maclaurin" series) some of which are constant, some of which are functions of the first power, some of the second, and some of the third;—yet the author does better than that, for, in the second equation for the total energy supplied, he has very cleverly, indeed, eliminated all the higher powers, by finding *mean factors*, which are equal to the root mean square of the load, and the root mean cube of the load, and each of which factors, once determined, *is a constant*. I do not see how anything could be presented more simply and more intelligently than the author has presented this case.

I think, therefore, that the author deserves the very highest credit. This paper, in a few years, will be looked on as one of the classics in the art of the scientific study of power cost. We shall look back to it as one of the starting points and stepping stones in that science which needs so much development, and where so much progress is to be made. When we realize that eighty-five per cent of the fuel that is expended in the boiler room goes up the chimney, so to speak, and we practically make no measurement, make no attempt to find out what becomes of it, we should appreciate, and those of us who have had experience do appreciate,—the great effort put forth by Mr. Stott and his able mechanical staff to get at the root of the matter, and to begin a systematic study in an untrodden field of knowledge, where there is so much to be learned and so much saving to be made. The author has done very fine pioneer work. Instead of criticising him for having done so little, let us rather congratulate and thank him for having really accomplished so much in the direction of rationalizing the general principles of power station economy, so that he may be encouraged to continue his very commendable efforts in the pursuit of a "general solution" of the problem of power economics.

Reference has been made this evening to the difficult question of rating. Mr. Stott himself made some pertinent and opportune remarks on that question. Few realize the difficulties which lie ahead of us in arriving at an intelligent solution of the question of rating. We have here one of the great problems before the electrical engineer to-day. I will tell you something that will interest you all as showing the great difficulty involved in this matter,—as showing how much greater the difficulty is in arriving at a consensus of opinion on the matter of rating than most people imagine. In 1906 there was formed an International Electrotechnical Commission, as the result of a vote taken at the

St. Louis Electrical Congress of 1904. That Commission was formed for the purpose of going into, and of discussing, questions which are of general interest and importance to the electrical arts and the electrical industries throughout the world, and upon which international agreement is desirable or necessary. The Commission was organized in London in 1906. The American Institute of Electrical Engineers, through two of its delegates, took a very active and effective part in the formation of the Commission; and it has taken an active part in the work of the Commission ever since. It has, in fact, assumed the task of representing and safeguarding the interests of American electrical industry abroad, through an American Committee, which is appointed each year by the President of the Institute, to represent this country in the meetings and deliberations of the International Electrotechnical Commission.

One of the great questions which came before that body—in fact it was thought at that time the principal question to be brought before it—was the question of determining ratings, so that the manufacturers of electrical machinery in any country might be able to know what they were running up against in sending their product to foreign countries. For instance, some manufacturers in certain countries would sell as a 10-h.p. or a 10-kw. machine, a machine which no American manufacturer would have had the " nerve " to sell for more than 7.5 h.p. or 7.5 kw. It was a question of rating—a question involving efficiency, maximum output, overload capacity, temperature—rise, etc.

It was thought that the Commission could easily arrive at some understanding on the question. It had not gone very far, however, before it found that the question of rating could not be gone into until after the ground had been prepared. It found, for instance, that it must first discuss the technical language which is in use all over the world, and bring about an understanding as to that language,—as to nomenclature, and as to symbols, and a lot of other things, simply for the purpose of laying the foundation work, and to prepare for an intelligent discussion and solution of the problem of rating. We must obviously begin by settling questions of technical terminology and language, and agree upon the fundamentals of rating before we can hope to arrive at any agreement on ratings. The Commission has been working thus far only on what might be termed the preliminaries to the question or international standardization and rating.

In the five years or more since the Commission was organized, it has made some progress, but we are still probably several years removed from the time when it will be possible to establish and to define the ratings of all electrical machinery. There are some things, of course, which it is much more easy to define, and on which international agreement may be expected in a relatively short time, but the question of boiler rating, the question

of engine rating, and the questions which Mr. Stott spoke of, present some difficulties that will be a long time in finding a definite and satisfactory solution. There are even some points on which international agreement looks almost impossible.

The paper of this evening is a valuable contribution to the preparations which must be made before some of the perplexing problems of ratings can be properly taken up and disposed of.

Let us hope that by the time the question of determining ratings of boilers and engines comes formally before the International Electrotechnical Commission the results obtained from, and the work following, the paper presented this evening, may be of great value in the presentation of that subject before the Commission, and be a useful means of throwing light on it and of leading to its definite, intelligent settlement.

Farley Osgood: I simply want to add a word in commendation of Mr. Rhodes' paper. I have not the fear that our friend Mr. Lincoln has, that the manufacturer will be obliged to give us a 200 per cent rating. I have the regret that he will not be able to do it.

As I interpret the paper, Mr. Rhodes has used the higher powers and carried them up to what might be termed excess in the matter of overload, merely to bring out clearly the facts set forth in his curves and his calculations; and although his formulas may at first seem somewhat startling as to length, I believe that only in this way can we gather in properly all the variable factors which affect the cost.

We all know the many items in the cost sheet, and the solution of each item is to be obtained and put in its proper place in the general calculation, so that when his suggested calculation is carried to completion, we will have, as Mr. Mailloux has said, not a complicated answer, but a simple answer, which may be reduced to one or two factors. The value of this paper will come home to us when we have time to more clearly understand it and compare it with our own detail or monthly operating costs, as they come to us, and when we learn how to apply his principles of calculation and compare them with our former methods of calculation, so that when all is said and done, Mr. Rhodes has shown us, by extended factors and extended curves, an interesting and effective picture of his method. We know that in even from 80 per cent to 100 per cent rating, or from 100 per cent to 125 per cent rating, a slight difference in the curve will make a great difference in dollars, when it is considered that the curves represent cost per kilowatt-hour; and when we think of the millions of kilowatt-hours used, as a total, we begin to get the absolute effect of such difference on our cost sheet.

In this paper is described a method by which we will be able to determine, after some calculation, and the use of the one or two factor scheme, the chief variables in our cost sheets, so that having completed the calculation as a formula, we can promptly determine wherein our losses are occurring; and I think we

certainly owe Mr. Rhodes a vote of thanks for his ideas as set forth in this paper, because if they work out, and he says they will, and I believe they will, we will be saved a great deal of time in getting at those costs which most affect our economies.

G. I. Rhodes: The author can add little to the discussion of the paper. Suggestions and criticisms have been made by the various speakers and in a large part answered by those succeeding.

It has been brought forcibly to our attention that there is no particularly well defined and logical method of determining or expressing the rating of apparatus. The rating used in the paper was that of greatest economy in the prime mover and that of ten square feet of surface per boiler horse-power. The plea for greatly increased overload capacity will be satisfied by the ratings used above if the horse-power or kilowatts per dollar are increased in a like proportion. The progress of the art has not only increased the kilowatts per dollar, but by improved method has actually increased the kilowatts per pound of material and in numerous cases increased the capacity of existing apparatus. It is hardly to be expected that engineering will cease to progress along these lines.

This paper was designed solely to present a possible method of comparing power costs in a more logical method than is commonly used, and can be considered only as a beginning. The determination of the desirability of high overload capacities, even at the expense of poor economy, was made to illustrate how the method might be used in a particular instance. It is to be hoped that some time we will be able to determine exactly the cost of taking on any particular load or the saving produced by economical use of power. At present such a determination is unsatisfactory and will continue to be so until a more logical method of presenting power costs is devised.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

REPORT OF THE BOARD OF DIRECTORS FOR THE FISCAL YEAR ENDING APRIL 30, 1912

The Board of Directors of the American Institute of Electrical Engineers herewith presents to the members of the Institute its annual report for the fiscal year ending April 30, 1912.

Brief summaries of the work of the various standing and special committees are included in the report, and also a detailed financial statement showing the condition of the respective funds of the Institute, the receipts and disbursements for the year, the assets and liabilities, and a condensed cash statement.

Notwithstanding the fact that the disbursements for the year far exceed those of all previous years, as a result of the constantly increasing activity and scope of the Institute, there is an excess in the receipts over the disbursements of **$5,574.35.**

Upon recommendation of the Finance Committee, the Institute purchased for investment, in June 1911, $15,000 par value Wilmington, Del., 4½ per cent. registered bonds.

The Board of Directors has held nine regular monthly meetings at Institute headquarters during the year, and one meeting at the Chicago Convention in June 1911.

The Annual Convention was held in Chicago June 26–30, 1911. The registered attendance was 578 members and 386 guests, a total of 964, which was the largest convention attendance in the history of the Institute.

The Pacific Coast Meeting was held in Portland, Oregon, April 16–20, 1912, and was attended by 210 members and guests, including delegations from all the principal Pacific Coast cities.

A three day meeting under the auspices of the Pittsburgh Section and the Industrial Power Committee, in conjunction with the Association of Iron and Steel Electrical Engineers, was held in Pittsburgh April 25–28, 1912. The attendance at this meeting was 265.

At the Chicago, Portland and Pittsburgh meetings, in addition to the large number of excellent papers presented and discussed, the programs included inspection trips and other interesting features arranged by local committees, which were both enjoyable and profitable to all who participated.

During the year President Dunn presided at the Pittsburgh meeting and at the Pacific Coast meeting at Portland. He also visited the Sections at Ithaca, Cleveland, Boston, San Francisco, Los Angeles, St. Louis and Lynn.

At the Chicago Convention the resignation of Mr. Ralph W. Pope,

as Secretary of the Institute, was tendered and accepted, and the Board of Directors, in recognition of Mr. Pope's long and loyal services to the Institute, appointed him to the position of Honorary Secretary, in which capacity the Institute still has the benefit of his long experience in its affairs.

Mr. Pope devotes his time principally to the welfare of the Sections and Branches, and during the year he has visited the following Sections: Ithaca, Schenectady, Chicago, Cleveland, Toledo, Washington, Minnesota, Indianapolis-Lafayette, Los Angeles, San Francisco, Portland, Seattle, and Vancouver; also the Branches at Armour Institute and Lewis Institute, Chicago, and Throop Polytechnic Institute, Pasadena. Upon his return trip from the Pacific Coast Convention at Portand he also addressed a meeting of members at Spokane, Wash., where a movement is on foot to establish a Section.

At the first meeting of the Board of Directors in the present administrative year, held on August 22, 1911, there was inaugurated a policy of publicity in Institute affairs, and accordingly a resumé of the actions of the Board has been sent to the technical press and all Directors and members of committees immediately after each meeting.

Mr. S. Z. de Ferranti, President of the Institution of Electrical Engineers, of Great Britian, visited this country in September, 1911, in company with several other prominent engineers. A luncheon in honor of the distinguished guest was given by the Institute officers and past-presidents in New York on September 29th.

A delegation of Institute members attended the International Electrical Congress and the meeting of the International Electrotechnical Commission held in Turin, Italy, in September, 1911. Reports of both meetings were published in the November, 1911, issue of the Institute PROCEEDINGS.

At the October meeting of the Board of Directors, the President was requested, in view of the cordial hospitality shown by the Italian authorities and members of the Associazione Elettrotecnica Italiana to the representatives of the United States and the American Institute of Electrical Engineers attending the Congress at Turin, to appoint a committee to draft suitable resolutions expressing the appreciation of the Institute for the honors and distinctions the American representatives had received. In reporting these resolutions at the November Board meeting the committee suggested that in the case of the Associazione Elettrotecnica Italiana a more substantial evidence of appreciation and good will would be fitting and desirable, and recommended the presentation to the Associazione of a bust of Joseph Henry. Arrangements have been made for the formal presentation of the bust at the Annual Meeting on May 21.

A bronze bust of the distinguished German scientist, Hermann von Helmholtz, was presented to the Institute last fall by Mr. Edward D. Adams, to whom the Institute is indebted for many benefactions in the past. The formal presentation of the bust to the Institute was the feature of the Institute meeting held in New York in November 1911. The Verband Deutscher Elektrotechniker was represented at the meeting by Dr. Adolf Franke of Berlin.

On October 13, 1911, resolutions were adopted by the Board directing the Editing Committee to regard as standard practise and to continue the insertion in its publications of metric equivalents, after each expression of values in English measures; also that the Institute adopt the standard international symbology decided upon by the International Electrotechnical Commission; also that the Institute adopt as the standard direction for expressing advancement of phase in graphic diagrams of alternating-current quantities the counter-clockwise direction standardized by the International Electrotechnical Commission.

The President was also authorized to correspond with the officers of the leading European societies of electrical engineers with a view to establishing reciprocal visiting member privileges for the mutual advantage of European electrical engineers visiting the United States and American engineers visiting the various countries of Europe.

At the November 1911 meeting of the Board a new By-law was adopted providing for preliminary nominations of officers of the Institute by petition. This has met with general approval, as was evidenced in the recent nominations for officers for 1912–1913.

On January 12, 1912, Mr. F. L. Hutchinson, formerly Assistant Secretary, and Acting Secretary since Mr. Pope's resignation, was appointed by the Board of Directors as Secretary of the Institute, to fill the unexpired term of Mr. Ralph W. Pope.

The Board also unanimously approved the proposed amendment to the Constitution providing for the appointment of the Secretary by the Board instead of his election by the membership, and directed that this amendment be submitted to the membership for a vote.

At the same meeting, in accordance with the provision of the Constitution by which Honorary Members may be chosen from among those who have rendered acknowledged eminent service to electrical engineering, Professor Andre Blondel, of Paris, Mr. C. E. L. Brown, of Baden, Switzerland, Dr. Emil Budde, of Berlin, Mr. Sebastian Z. de Ferranti, of London, and Professor Antonio Pacinotti, of Pisa, Italy, were elected Honorary Members. These were the first names to receive the distinction of honorary membership since 1892.

A trip to the Panama Canal for members and their guests was authorized by the Board last fall, and on January 17, 1912, a party of 59 members and guests sailed from New York on the steamer Almirante. Another party of 51 members and guests left New Orleans on the steamer Cartago on January 20. The parties combined at Panama, and were afforded unusual facilities for inspecting the engineering features of the great canal. A report of the trip was published on page 283 of the March PROCEEDINGS.

On February 9, the Board adopted a resolution recognizing the propriety of permitting the use to the members of the columns of the PROCEEDINGS for the expression of their criticisms and views on Institute affairs. Since the passage of this resolution "The Forum" has been used to a considerable extent for the discussion of various questions, particularly the constitutional amendments.

In addition to the work mentioned in this report, much has been accomplished by the various permanent and special committees as re-

ported from time to time in the Institute PROCEEDINGS. From the foregoing statements and the following brief reports of the work of many of the committees, it will be seen that the Institute's field of activity is constantly broadening, and that a vast amount of useful work has been accomplished during the past year.

Sections Committee.—The Sections Committee is able to report an increased activity in its work during the past year. In line with similar statements of previous years, the activities of the Sections Committee are summarized in the following table.

	Year Ending				
	May 1 1908	May 1 1909	May 1 1910	May 1 1911	May 1 1912
SECTIONS					
Number of Sections..........	21	24	25	25	28
Number of Section meetings held......................	141	169	187	208	231
Total attendance............	7,476	16,427	16,694	15,243	19,800
BRANCHES					
Number of Branches.........	22	26	31	36	42
Number of Branch meetings held......................	143	198	237	255	281
Attendance.................	4,128	8,443	10,255	10,714	10,255

The foregoing table does not show by any means all of the increased activities of our various Sections. Not only has the amount of work increased as indicated in the foregoing table, but the character has during the last year or two shown a marked improvement. The number of original papers which is being produced by our various Sections is increasing to an astonishing degree. Practically every Section now has presented at its meetings original papers of a value which is comparable to that of the papers presented at the regular Institute meetings. Not only have the Section meetings themselves shown increased activity and improved character, but the recent movement to hold regular Institute meetings in various parts of the country has done much to stimulate Section activity. In addition to the regular Section meetings shown in the preceding summary, regular Institute meetings have been held in Boston, Mass., Portland, Oregon, Pittsburgh, Pa., and in Schenectady, N. Y. Some of these meetings have occupied a period of three days.

As indicated in the summary, three new Sections have been added during the past year; namely, at Lynn, Mass., Indianapolis-Lafayette, and Vancouver, B. C. These new Sections have taken hold well, and already 20 meetings, with a total attendance of 2,249, have been held by these three new Sections.

Six new Branches have been added during the year as follows: University of California, Ohio Northern University, Oklahoma Agricultural and Mechanical College, Rose Polytechnic Institute, University of Virginia, and Yale University.

The uniform basis of Section expenditures which was adopted a year ago is working to the satisfaction of all concerned.

In brief, the Sections Committee reports a satisfactory year.

Meetings and Papers Committee.—During the year this committee has arranged for eight regular meetings in New York, and has co-operated in and approved the programs for the Pacific Coast Meeting held in Portland, Ore., April 16th to 20th, 1912, and the Industrial Power Meeting held in Pittsburgh, April 25th to 27th, 1912. A total of thirty technical papers were presented and discussed at these meetings. The committee has also approved the plans and program for the meeting to be held in Schenectady, N. Y., on May 17th. At this meeting, which is under the auspices of the Schenectady Section, ten papers will be presented.

At the 1911 Annual Convention held in Chicago under the auspices of last year's committee, 35 technical papers were presented. Preparations are now being made for the 1912 Annual Convention to be held in Boston, June 24th to 28th, at which about 35 papers upon a wide variety of subjects will be presented. The program will include joint sessions with the Illuminating Engineering Society and the Society for the Promotion of Engineering Education.

New York Reception Committee.—This committee was established by the Board of Directors in December, 1911, to raise funds for and to take charge of the smokers which have been held in the Institute rooms immediately after the technical sessions at the New York meetings. These smokers have enjoyed an increasing popularity very greatly increasing the attendance at the meetings and affording an excellent opportunity for social intercourse of members and their guests. The finances to defray the expenses of the smokers have been collected by the Reception Committee in the form of voluntary contributions.

This committee also arranged for a dinner which was attended by members of the Board of Directors and several Past-Presidents on April 1st, 1912, in honor of Mr. C. E. L. Brown, of Switzerland, who had recently been elected an Honorary Member of the Institute.

Railway Committee—The committee avoided any efforts to obtain papers which would not add materially to electric railway information, or which might be in the nature of duplication of other papers.

One notable contribution along a new line was arranged for by the committee; that by President Samuel Insull of the Commonwealth Edison Company, on the general subject of consolidating power plants, and treating the railway demands, whether urban, interurban or trunk line, simply as large customers in a general system. On the presentation of this paper it was decided to have it revised and printed for presentation at the Annual Convention in Boston in June for discussion.

Realizing that much of the opposition to the electrification of trunk line railways is due to lack of detailed operative information, as well as figures of first cost of installation, a series of blanks have been prepared by a sub-committee which it is hoped may be filled up by the various important steam railways operating electrical sections so that there may be strictly comparative information at hand.

High-Tension Transmission Committee.—Every Section and Branch has held a special meeting on high-tension transmission work, and there

has been an extremely broad and general discussion of all active high-tension subjects. There is to be a regular Institute meeting at Schenectady in May, half of which will be devoted to high-tension transmission work, and a session will also be devoted to the subject at the Annual Convention at Boston in June. There has been a great deal of correspondence with different Sections and Branches, and in many cases speakers have been arranged for by the committee.

Electric Lighting Committee.—The Electric Lighting Committee has obtained five papers during the year on electric lighting subjects. One of these was presented at the Pacific Coast Meeting held in Portland, Oregon, in April, and the other four will be presented at the Institute's Boston Convention in June.

Industrial Power Committee.—The Industrial Power Committee organized in Pittsburgh, in connection with the Pittsburgh Section, a joint meeting with the Association of Iron and Steel Electrical Engineers. The meeting was held April 25–27, and 10 papers on various subjects relating to industrial power were presented. The committee has also obtained a number of papers for presentation at the Annual Convention.

Telegraphy and Telephony Committee.—This committee has held one meeting during the year, and has carried on considerable correspondence. The committee has obtained a number of valuable papers dealing with telegraphy and telephony. Some of these were presented at the Pacific Coast Meeting in Portland, Oregon, in April, and others will be presented at the Annual Convention in Boston in June.

Power Station Committee.—It was the intention of the Power Station Committee to have a meeting under its auspices at which would be presented a number of brief papers descriptive of the latest developments in the constituent parts of a typical large power station. As the season advanced, however, it was found that the amount and variety of material offered made it unnecessary to set aside a meeting for this specific purpose but the main items were covered in other meetings during the year.

Electrochemical Committee.—At the beginning of the season the Electrochemical Committee endeavored to get a sufficient number of papers on electrochemical subjects to devote one of the regular monthly meetings of the Institute in New York to electrochemistry. It was not possible to obtain the papers in time for such a meeting, and the committee therefore decided to postpone the presentation of the papers until the Annual Convention. The committee has succeeded in obtaining for the convention six papers, and a session will be devoted to the subject.

Electrophysics Committee.—This new committee was created by the Board in recognition of the fact that Electrophysics has ceased to be solely science and has become an important practical factor in electrical engineering. It was appointed late in the year and therefore has not been able to accomplish as much as it might have done if appointed at the usual time. No meetings have been held during the few months that elapsed since the committee was appointed, but it has secured a number of papers on various subjects included within the field of electrophysics for the Boston Convention, and it is believed that next year's committee on electrophysics will find it possible to secure a larger number of valuable papers on this subject.

Educational Committee.—The Educational Committee was reorganized on account of the resignation of the original chairman and the appoint-

ment of his successor last October. At the first meeting thereafter, it was decided to take up the consideration and study of vocational and industrial education in the United States. The subject was divided into parts, as follows:

A study of the present schools now established in which distinction is made between those maintained by industrial corporations for their own purposes, those maintained by public taxes, and those maintained by private benevolences; the second part, a study of the laws in existence for the establishment and maintenance of vocational schools; third, from the data gathered, the presentation of such elementary principles as appear from experience to be wise in the development of this particular form of education.

The committee divided the country into several sections and members were assigned to sections for gathering data and information with regard to existent schools. A member of the committee was assigned for the project of gathering together all laws on vocational education at present existent in the United States. Much work has been done by the committee as above outlined and arrangements have been made with the Meetings and Papers Committee to have the results presented at the Annual Convention.

Editing Committee.—Since April 30, 1911, there have been edited and published 12 numbers of the PROCEEDINGS. The total number of pages contained in these PROCEEDINGS is 2,582. Of these, 404 pages have appeared in Section I, and 2,178 in Section II. Volume XXX of the TRANSACTIONS, consisting of the papers and discussions presented during the calendar year 1911 and the report of the Board of Directors for the fiscal year ending April 30, 1911, will be issued in three parts, and will contain about 2,700 pages, more than any previous volume of the Institute TRANSACTIONS. With the third part still to be printed, the first two parts contain 1,742 pages, only six pages less than the whole of Volume XXIX.

The reports and discussions submitted by the Sections and Branches, and the discussions presented at the regular Institute meetings, have been edited and published under the supervision of the Editing Committee.

Standards Committee.—The Standards Committee has held monthly meetings in New York. It was voted that no new edition of the Standardization Rules should be issued this year. A sub-committee was, however, appointed to collect material for a complete revision of the Rules.

A post-card invitation was issued from the Institute office to all Members and Associates requesting that suggestions for amendments and modifications in the Rules should be forwarded to the secretary of the committee, with a view of being included, if approved, at the next revision.

A special sub-committee was also appointed to consider the modifications in the Rules for the rating of machinery.

The following subjects have occupied the attention of other special sub-committees during the year: electric cable terminology, definitions for the Committee on Code of Principles of Professional Conduct, cooperation with like committees of other societies, international copper resistivity standards, questions of international nomenclature and international rating. Action was taken on some of the above subjects, as well as on others not included in the list.

Communications have been held with the Bureau of Standards, and also with the American Society for Testing Materials, in regard to the preparation of a new electrical table of copper wires.

Communications have also been exchanged with the U. S. National Committee of the International Electrotechnical Commission.

Code Committee.—The Code Committee held a meeting on March 12, 1912, with representatives of the National Electric Light Association, the Association of Edison Illuminating Companies, and the National Inspectors Association, and concurred in a joint recommendation to the National Fire Protection Association in regard to the grounding of secondaries.

On March 27, 1912, Mr. Farley Osgood, representing the A. I. E. E., attended the annual conference of the Electricity Committee of the National Fire Protection Association. Mr. Osgood's report is printed in full in the May PROCEEDINGS.

Law Committee.—The Law Committee, in its advisory capacity, has during the year presented its views with reference to the provisions of the Constitution bearing upon actions of the Sections; the publication of the names of candidates for nomination, and the management of the library; also upon certain proposed amendments of the Constitution with reference to the appointment of the Secretary by the Board of Directors, and providing for an additional grade of membership. The committee has also presented its opinion with reference to the Code of Principles of Professional Conduct.

Under the Constitution, the Law Committee, being an advisory committee, has undertaken no constructive work other than such as may be involved in the consideration of the subjects brought to its attention.

Library Committee.—The complete report of the Library Committee will be found on page 1717 of this issue.

Public Policy Committee.—One of the first acts of the Board was to create a Public Policy Committee to which could be referred the increasing number of important issues affecting the Institute's public relations.

On November 10, 1911, the Board referred to this committee an invitation to the Institute from the National Waterways Commission of the U. S. Congress, to take part in a hearing at Washington, D. C. on November 21, 1911.

A sub-committee of the Public Policy Committee consisting of President Gano Dunn and Mr. H. W. Buck prepared a preliminary report of its views on the development of water powers, which draft was modified by the Public Policy Committee and its Advisory Members to conform to and represent their joint opinion. President Dunn and Messrs. H. G. Stott, chairman, Calvert Townley, Lewis B. Stillwell, and John H. Finney, members of the committee, represented the Institute at the hearing in Washington. The brief presented by the Institute delegation and a report of the hearing were published in the December, 1911, PROCEEDINGS.

The Institute representatives were given the first hearing on the afternoon of November 21 and the entire morning of November 22, and through them the thanks of Chairman Burton and other members of the Commission were transmitted to the Institute for the information given in the printed brief and for its representation at the hearing.

Patent Committee.—The Patent Committee was appointed but re-

cently and is not yet prepared to make a final report. Thus far the work of the committee has been accomplished by correspondence between the chairman and the members of the committee. Four members of the committee acted as conferees at an important conference on patent matters held in Washington on April 15 and 16 at the call of the Patent Law Association of Washington.

This committee was established by the Board of Directors as a result of the initiative of the St. Louis Section in urging improvements in the patent laws of the United States.

Code of Principles of Professional Conduct.—Originally this committee was known as the Committee on a Code of Ethics. Its appointment was the result of a discussion at the Milwaukee Convention, held in May 1906, following the presidential address of Dr. Schuyler Skaats Wheeler, on "Engineering Honor." It was the sense of the convention at that time that the ideas expressed in Dr. Wheeler's address should be embodied in a code of ethics for the electrical engineering profession. A code was prepared and discussed at the Niagara Falls Convention held in June 1907. Later in the same year the code was revised, printed and submitted to the membership for suggestions.

No further action was taken on the code until June 1911, when in accordance with a resolution of the Board of Directors, President Jackson appointed a committee to take up the question. The committee was reappointed by President Dunn the following August on his accession to office.

This committee's work was presented in a report to the Board of Directors on February 9, 1912, when a code of principles was tentatively adopted. After a month's careful analysis and consideration of numerous suggestions from the advisory members of the committee and others the present code as printed in the April PROCEEDINGS was adopted at the meeting of the Board of Directors on March 8, 1912.

The name of the committee was changed on February 9, 1912, to the Committee on Code of Principles of Professional Conduct.

The committee is now considering suggestions which have been submitted to it since the adoption of the code.

Relations of Consulting Engineers.—The Committee on Relations of Consulting Engineers has considered at its several meetings the matters referred to it, also the proper procedure and general scope of its work. The committee expects to be able to formulate its recommendations after further conferences with the representatives of other societies and of the various interests concerned.

United States National Committee of International Electrochemical Commission.—The president and secretary of the Committee, with President Dunn of the Institute, attended the meeting of the I. E. C. at Turin (September 7–13, 1911) as delegates from the United States. A provisional report of the meeting was submitted by the secretary of the committee to the Institute's Board of Directors, in October, and was published, by their direction, in the November issue of the PROCEEDINGS, Vol. XXX, No. 11, pages 2437–2448.

A brief official resume of the Turin meeting, in French and English, was printed and issued by the central office of the I. E. C., in London, in November, 1911, marked Publication 12.

At that meeting the U. S. National Committee communicated, through President Dunn, to the I. E. C., a cordial invitation from the American Institute of Electrical Engineers to hold a meeting in San Francisco in 1915. This proposal was formally adopted.

Under the instructions of the Board of Directors, the last edition of the Standardization Rules, issued by the Institute this year, contains a brief resume of the decisions of the Turin meeting, and also a slightly abridged copy of the Central Office's publication No. 9, on " Rating of Electrical Machinery," being extracts from the rules of various countries.

At the Turin meeting the I. E. C. appointed three international special committees on the subjects of " Nomenclature, " " Symbols, " and " Rating of Machinery, " respectively, to report at the next plenary meeting in Berlin in 1913.

The United States Committee endeavored to have delegates attend meetings of the two latter special committees. After some delays, President C. O. Mailloux left New York on April 24, to attend, as U. S. delegate, the meeting of the "Committee on Rating of Machinery" at Paris, set for May 8.

The committee has secured from the Treasury Department at Washington an order that all official reports of the I. E. C. may be admitted free of duty into the United States, as scientific publications, under paragraph 517 of the Tariff Act.

The committee has held monthly meetings in New York City. It has carried on a considerable amount of correspondence with the Central Office and of communication with the Standards Committee.

International Electrical Congress, San Francisco, 1915.—The project of holding an International Electrical Congress during the Panama Exposition at San Francisco in 1915, first took shape in the Spring of 1911 when a group of Pacific Coast members organized and sent Mr. H. A. Lardner as a delegate to bring it to the attention of the Institute officers in New York. This matter was first brought to the attention of the Board at the June, 1911, meeting, at which a committee was appointed to consider the matter. Upon the recommendation of this committee the Board adopted resolutions in August, 1911, to the effect that the Institute should initiate and organize such a congress under the authority of the International Electrotechnical Commission. The desired authority was granted by the latter body at its meeting in Turin in September, 1911.

The following officers of the Committee on Organization of the Congress have been appointed by the President: Dr. Charles P. Steinmetz, President; Dr. A. E. Kennelly, Vice-President in Charge of Program; Mr. C. O. Mailloux, Vice-President in Charge of International Relations; Mr. W. D. Weaver, Vice-President in Charge of Organization; Mr. Henry A. Lardner, Vice-President in Charge of Pacific Coast Relations; Dr. E. B. Rosa, Secretary; Mr. Preston S. Millar, Treasurer and Business Manager.

John Fritz Medal.—The John Fritz Medal for 1911 was awarded to Sir William Henry White, for " notable achievements in naval architecture. " The presentation was made at a dinner of the Society of Naval Architects and Marine Engineers at the Waldorf-Astoria Hotel, New York, on Friday evening, November 17, 1911. The attendance included representatives of the principal engineering societies of the United States.

Edison Medal.—The Edison Medal Committee, at its meeting held on November 20, 1911, selected from the names of the candidates submitted for consideration in accordance with its by-laws, the name of George Westinghouse, to be voted upon in December following.

At the meeting of the committee on December 15, 1911, a vote taken in accordance with its by-laws resulted in the award of the Edison Medal to Mr. George Westinghouse, "for meritorious achievement in connection with the development of the alternating-current system for light and power." The presentation of the medal is to be made at the Annual Convention to be held in Boston in June.

Indexing Transactions Committee.—The Indexing Transactions Committee has had prepared during the year synopses of all papers presented before the Institute up to and including the year 1910, and index cards have been prepared covering, in detail, the contents of these papers. The papers and cards have been largely classified and samples of typographical arrangement have been obtained. The entire index will be ready for the printer this coming summer and should appear in the fall. There will be two parts to the index; one part covering papers up to and including 1900, and the second part, papers from 1901 to 1910 inclusive. The index for the year 1911 will appear in the volume for that year.

Additional Grade of Membership.—The Additional Grade of Membership Committee (originally appointed under the name of the Intermediate Grade of Membership Committee) has considered during the present administration the data collected by the committees of previous years, and, after further investigation and discussion, prepared a draft of amendments to the constitution for consideration by the Board of Directors at its December meeting. This report was then revised in the light of criticisms and suggestions obtained from members of the Board and others, and resubmitted at the January meeting of the Board. At this meet'ng, the last draft with slight modification was unanimously adopted by the Board and recommended for submission to the membership as a constitutional amendment.

The final form of the report was of the nature of a compromise between the rather widely varying views of the committee arrived at by vote at numerous meetings held. The substance of the amendments has been so fully set forth in various explanatory statements published in the PROCEEDINGS that no further explanation is here required. The duties of the committee, with the exception of assisting in expounding the amendments for the benefit of the membership, were practically completed with the acceptance of the amendments at the Board's January meeting.

Board of Examiners.—The Board of Examiners has held 10 meetings during the year. It has considered and recommended for action by the Board of Directors a total of 1616 applications of all classes. A summary of these applications is as follows:

Recommended for election as Associates	808
Not recommended for election as Associates	2
Recommended for transfer to the grade of Member	60
Not recommended for transfer to the grade of Member	25
Transfer applications considered but held for additional information	7
Recommended for enrolment as students	714
Total	1616

In addition to applications for admission and transfer, the Board has considered and reported upon a number of questions that have been submitted to it by the Board of Directors during the year.

Membership.—A circular letter was mailed to each member of the Institute on November 28, 1911, asking for names of desirable candidates for admission to membership. The co-operation of Section officers was also enlisted. As a result, over 1,200 names were received at Institute headquarters. Each of these candidates was communicated with promptly and supplied with literature relating to the Institute and the advantages of membership.

The total number of applications received during the year is 1,025. A complete report showing the total membership, the additions and deductions, and the net increase for the year is given below.

	Hon. Mem.	Mem.	Assoc.	Total
Membership, April 30, 1911.	1	689	6,427	7,117
Additions:				
Honorary Members	4			
New Associates			855	
Transferred	1	49		
Reinstated		1	27	
Deductions:				
Died	1	3	29	
Resigned		6	150	
Dropped		5	351	
Transferred		1	49	
Membership, April 30, 1912	5	724	6,730	7,459

Net increase during the year in membership 342

Deaths.—The following deaths have occurred during the year:

Honorary Member.—Antonio Pacinotti.

Members.—C. D. Haskins, E. W. Mix, W. D. Sargent.

Associates.—E. H. Anderson, Edwin H. Bennett, E. H. Berry, D. E. Black, E. B. Boor, W. R. Brixy, Lon D. Caldwell, F. T. Clarke, C. C. Cokefair, E. Copley, F. S. Davenport, I. T. Dyer, H. W. Fellows, J. B. Fleming, L. A. Freudenberg, W. C. Getz, H. L. Hart, Junzo Itoh, W. S. Johnson, E. M. Kenly, M. McIntyre, O. C. Poste, Roger P. Stebbins, H. H. Sykes, R. H. Thomas, E. G. Tracy, R. A. Turner, G. A. Wilson, Chas. I. Young.

Total deaths, 33.

Resignations.—Resigned during the year in good standing: Members, 6; Associates, 150; total 156.

Delinquents.—Dropped as delinquent during the year, 356.

Finance Committee.—The following correspondence and financial statements form a complete summary of the work of the Finance Committee for the year.

New York, May 14, 1912.

Board of Directors,

American Institute of Electrical Engineers.

Gentlemen: Your Finance Committee respectfully submits the following report for the year ending April 30, 1912.

During the past year the committee has held monthly meetings, has passed upon the expenditures of the Institute for various purposes,

and otherwise performed the duties prescribed for it in the Constitution and By-laws. Peirce, Struss and Company, chartered accountants, have audited the Institute books and their certification of the Institute finances follows.

In company with your Secretary and a member of the firm of chartered accountants, the committee has examined the securities held by the Institute and find them to be as stated in the accountants' report.

In accordance with the authority of the Board an investment from the surplus funds of the Institute was made during the past year amounting to **$15,000.00** par value Wilmington City 4½ per cent registered bonds.

The expenditures of the Institute during the past year have been considerably increased due to the constantly broadening scope and activity of the organization, and particularly due to the increased amount of technical material published in the PROCEEDINGS and TRANSACTIONS resulting from the extension of the policy inaugurated a few years ago of holding Institute meetings in various parts of the country. Notwithstanding the increased budget of expenditures made necessary by reason of these extended activities, it is gratifying to note that the accompanying increase in income has resulted in a comfortable surplus for the fiscal year.

Respectfully submitted,
A. W. BERRESFORD
Chairman, Finance Committee.

MR. A. W. BERRESFORD, NEW YORK, May 10, 1912.
Chairman Finance Committee.

Dear Sir: In accordance with your instructions, we have audited the books and accounts of the American Institute of Electrical Engineers for the year ended April 30th, 1912.

The results of this examination are presented in four exhibits, attached hereto, as follows:

Exhibit "*A*" Balance Sheet, April 30th, 1912.

Exhibit "*B*" Receipts and Disbursements for general purposes for year ended April 30th, 1912.

Exhibit "*C*" Receipts and Donations for designated purposes, also expenditures for year ended April 30th, 1912.

Exhibit "*D*" Condensed Cash Statement.

We beg to present, attached hereto, our certificate to the aforesaid exhibits.

Yours very truly,
(Signed) PEIRCE, STRUSS & Co.
Certified Public Accountants.

MR. A. W. BERRESFORD, NEW YORK, May 10, 1912.
Chairman Finance Committee.

Dear Sir: Having audited the books and accounts of the American Institute of Electrical Engineers for the year ended April 30, 1912, we hereby certify that the accompanying Balance Sheet is a true exhibit of its financial condition as of April 30th, 1912, and that the accompanying statements of Cash Receipts and Disbursements are correct.

(Signed) PEIRCE, STRUSS & Co.
Certified Public Accountants.

AMERICAN INSTITUTE OF
BALANCE SHEET,

EXHIBIT A

ASSETS

CASH:		
Land, Building and Endowment Fund	$5,307.53	
General Library Fund	271.15	
Life Membership Fund	4,827.28	
		10,405.96
General Cash in Bank	9,277.02	
Mailloux Fund, Interest	78.55	
Weaver Donation	6.69	
International Electrical Congress of St. Louis Library Fund, interest	372.72	
Total Cash deposit	9,734.98	
Secretary's Petty Cash on hand	750.00	
		10,484.98
Land, Building and Endowment Fund, accrued interest	55.28	
General Library Fund, accrued interest	2.82	
Mailloux Fund, accrued interest	22.50	
International Electrical Congress of St. Louis Library Fund, accrued interest	45.00	
Life Membership Fund, accrued interest	40.00	
		165.60
Mailloux Fund, principal (Bond)		1,000.00
International Electrical Congress of St. Louis Library Fund, N. Y. City 4½% Bonds, due 1917		2,268.00
New York City 4½% Gold Bonds, due 1957, par	30,000.00	
Premium on N. Y. 4½% Gold Bonds	1,952.50	
Chicago, Burlington & Quincy 4% Bonds, due 1958 (par value $15,000)	14,606.25	
City of Wilmington, Del. 4½% Bonds, due 1934	15,000.00	
Premium on City of Wilmington, Del. Bonds	997.50	
Westinghouse Elec. & Mfg. Co's stock	50.00	62,606.25
Equity in Engineering Societies Building (25 to 33 West 39th Street)	353,346.61	
One-third cost of land (25 to 33 West 39th Street)	180,000.00	
		533,346.61
Library Volumes and Fixtures	30,905.78	
Transactions	9,008.50	
Office Furniture and Fixtures	7,915.64	
Works of Art, Paintings, etc.	2,656.35	
Badges	463.35	
		50,949.62
ACCOUNTS RECEIVABLE:		
Members for current dues	240.00	
Members for past dues, suspense account	8,132.00	
Members for entrance fees	115.00	
Special	76.32	
Miscellaneous	265.65	
Advertising	2,016.25	
Accrued interest on bonds	831.25	
Accrued interest on bank balance	132.19	
		11,808.66
Total		$683,035.68

ELECTRICAL ENGINEERS
April 30, 1912

Liabilities and Surplus

Funds:		
Land, Building and Endowment Fund	$5,362.81	
General Library Fund	273.97	
Life Membership Fund	4,867.28	
Mailloux Fund	1,101.05	
International Electrical Congress of St. Louis Library Fund:		
Bonds	2,268.00	
Cash on deposit	372.72	
Accrued interest	45.00	
		$14,290.83
Reserve for Furniture and Fixtures		2,946.39
Accounts Payable, subject to approval by the Finance Committee		6,984.68
United Engineering Society (for cost of land)		54,000.00
Total Liabilities		78,221.90
Surplus:		
In Cash	9,277.02	
New York City Bonds	31,952.50	
C. B. & Q. Bonds	14,606.25	
City of Wilmington, Del. Bonds	15,997.50	
In property and accounts receivable	532,980.51	
		604,813.78
Total Liabilities and surplus		$683,035.68

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Receipts and Disbursements for General Purposes for Year Ended April 30, 1912

Exhibit B

Receipts

Entrance Fees.....	4,303.00	
Current Dues.....	66,879.00	
Past Dues.........	4,102.50	
Advance Dues.....	450.00	
Students Dues.....	4,113.00	
Transfer Fees.....	500.00	
Badges............	1,740.00	
		$82,087.50
Sales, Transactions etc..............	1,347.43	
Subscriptions, Proceedings.........	2,084.50	
Advertising.........	9,513.41	
Binding............	138.00	
Exchange..........	19.31	
		13,102.65
Interest:		
Bonds.........	2,625.00	
Bank Balance	597.48	
		3,222.48
Total.........		$98,412.63

Disbursements

Stationery and Printing.........	4,425.85	
Postage...........	2,849.85	
General Expense...	2,582.27	
Meeting Expense..	5,034.21	
Section Meetings..	9,271.33	
Badges purchased.	1,643.72	
Salaries...........	11,821.00	
Indexing Transactions...........	822.20	
Interest on Mortgage............	2,160.00	
Office Furniture and Fixtures....	981.04	
Adver. Expense....	3,339.41	
Year Book and Catalogue.......	2,896.86	
Express...........	220.87	
Interest refunded..	71.25	
		$48,119.86
Proceedings:		
Printing.........	7,934.32	
Paper and Envelopes..........	6,002.84	
Engraving......	1,663.34	
Binding and Mailing.......	4,137.31	
Salaries.........	4,084.00	
		23,821.81
Transactions:		
Vol. 29.........	8,135.76	
Vol. 30.........	4,413.03	
		12,548.79
Library (including salaries)		3,847.82
United Engineering Society Assessments for office space		4,500.00
Total.....................		$92,838.28
Excess of Receipts over Disbursements...............		5,574.35
		$98,412.63

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Receipts and Donations for Designated Purposes, also Expenditures for Year Ended April 30, 1912

Exhibit C

Receipts	
Land, Building and Endowment Fund, Donations, Interest, etc.	316.16
General Library Fund, Interest	6.63
Compounded Membership Fund	504.29
International Electrical Congress of St. Louis, Library Fund, Donations and interest	103.95
Mailloux Fund, interest	45.00
Certificate of Deposits	1,000.00
Total	1,976.03
Expenditures	
Mailloux Fund	7.80
Life Membership Fund	420.00
City of Wilmington, Del. Bonds and interest	16,087.50
Weaver Donation	58.75
Special Library Account	76.32
Total	16,650.37

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Condensed Cash Statement

Exhibit D

Cash on deposit April 30, 1911	$29,240.93	
Secretary's Petty Cash, April 30, 1911	750.00	
		$29,990.93
Receipts for general purposes, Exhibit "B"	98,412.63	
Receipts for designated purposes, Exhibit "C"	1,976.03	
		100,388.66
		130,379.59
Disbursements for general purposes, Exhibit "B"	92,838.28	
Expenditures for designated purposes, Exhibit "C"	16,650.37	
		109,488.65
Balance on hand April 30, 1912		20,890.94
On deposit for designated purposes, Exhibit "A"	10,405.96	
* On deposit in General cash, Exhibit "A"	9,734.98	
Secretary's Petty Cash, Exhibit "A"	750.00	
		20,890.94
Property acquired during the year, Office Furniture and Fixtures	981.04	
* This includes the following unexpended balances:		
Mailloux Fund	78.55	
Weaver Donation	6.69	
Int. Elec. Congress of St. Louis Library Fund	372.72	
		457.96

RECEIPTS AND DISBURSEMENTS PER YEAR PER MEMBER

During each fiscal year for the past seven years.

Year	**1906**	**1907**	**1908**	**1909**	**1910**	**1911**	**1912**
Membership, April 30, each year	3870	4521	5674	6400	6681	7117	7459
Receipts per Member	$12.77	$12.21	$13.01	$13.21	$13.35	13.37	$13.19
Disbursements per Member	10.48	11.62	11.73	10.49	12.03	11.03	12.44
Credit Balance per Member	$2.29	$.59	$1.28	$2.72	$1.32	$2.34	$.75

Respectfully submitted for the Board of Directors,

F. L. HUTCHINSON, Secretary.

New York, May 21, 1912.

REPORT OF THE LIBRARY COMMITTEE

For Year Ending April 30, 1912

Board of Directors, American Institute of Electrical Engineers.

Gentlemen:—In accordance with Section 24 of the By-Laws of the Institute we beg leave to submit herewith our annual report for the year ending April 30, 1912, showing the state of the library and including the names of all donors to it.

During the year a mezzanine floor with shelving capable of holding about 15,000 volumes has been erected at a cost of $6,196. The additional shelves have been filled with the books most frequently referred to; they are reached by a low staircase and the books are accessible to all readers. The appearance of the main room has been much improved by this addition and the efficiency of the service of the attendants has been increased thereby considerably. A number of additions have been made to the library furniture and a new system of illumination has been installed at a cost of $1,481.

A system of compilation of references to engineering literature, by special search through the publications in the library, has been inaugurated, the searches being made by the regular library attendants. Since its inauguration 181 such investigations have been made, most of them at the request of members residing outside of New York City. Duplicates of the related reports are kept on file and it has already been disclosed that several requests are likely to refer to the same subject matter.

The subject card catalogue of the Schuyler Skaats Wheeler collection is practically completed, a few minor items remaining to be entered.

The attendance has increased over the previous years, even though the main library room was closed for three months during the alterations and evening admission was prohibited during September, 1911.

The joint library of the Founder Societies now contains 50,000 volumes, receives currently 650 periodicals, and has over 1100 sets of periodicals and transactions. The growth amounts to about 3000 volumes per annum in all languages and this includes nearly all the worthy books issued in the restricted field which the library represents.

Statistical information concerning the library and its use during the year, including a list of donors, is given in the following tables:

Donors

May 1, 1911—April 30, 1912

ADAMS, E. D.	8
ADAMSON, D.	2
A. E. G. ZEITUNG	1

ALLGEMEINE ELEKTRICITAT GESELLSCHAFT	1
AMERICAN ELECTRIC RAILWAY ASSOCIATION	5
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS	8
AMERICAN SCHOOL OF CORRESPONDENCE	5
ARNOLD, BION J	7
BENEDICT, V. L.	3
BERLINER ELECKTRICITATS WERKE	1
BLAKISTON'S SON & COMPANY	1
CALDWELL, EDWARD	1
CANADA. COMMISSION OF CONSERVATION	1
CENTRAL STATION	1
DAVID WILLIAMS COMPANY	1
DIXON CRUCIBLE COMPANY	7
IOWA ELECTRICAL ASSOCIATION	1
IOWA ENGINEERING SOCIETY	1
ITALY. MINISTERIO DI AGRICOLTURA	1
KENNELLY, A. E.	2
MACMILLAN COMPANY	2
MAILLOUX, C. O.	63
MARYLAND. PUBLIC SERVICE COMMISSION	2
MASSACHUSETTS GAS & ELECTRIC LIGHT COMPANY	1
MCGRAW PUBLISHING COMPANY	1
NATIONAL ELECTRIC LIGHT ASSOCIATION	1
NATIONAL FIRE PROTECTION ASSOCIATION	1
NATIONAL FIRE PROTECTION ASSOCIATION	1
NEW ENGLAND WATER WORKS ASSOCIATION	1
NEW YORK STATE. DEPARTMENT OF LABOR	4
NEW YORK STATE LIBRARY	1
ONTARIO. HYDROELECTRIC POWER COMPANY	1
RUGBY ENGINEERING SOCIETY	2
SPON & CHAMBERLAIN	2
STONE & WEBSTER	1
U. S. DEPARTMENT OF AGRICULTURE	1
U. S. NATIONAL WATERWAYS COMMISSION	1
UNIVERSITY OF LONDON PRESS	1
UNIVERSITY OF MISSOURI	1
VAN NOSTRAND, D. COMPANY	9
VILLARS, G.	3
WEAVER, W. D.	3
DONOR UNKNOWN	1
OLD MATERIAL	30
	191

Exchanges	108	
Purchases and old material accessioned	191	
		299
Total accessions		490

The following tabulation gives the state of the accounts from which the Library Committee is entitled to draw.

Donations (General Library Fund)

Dr.		Cr.	
Balance May 1, 1911	$264.52		
Interest May 1, 1912	6.63	Unexpended	$271.15
	$271.15		$271.15

Mailloux Endowment Fund ($1000)

(Proceeds for the maintenance of certain sets of periodical publications)

Balance May 1, 1911	$41.35	Expended	$7.80
Interest	45.00	Unexpended	78.55
	$86.35		$86.35

International Electrical Congress of St. Louis, 1904, Fund

(Proceeds available for the purchase of non-American international electrical literature)

Invested in New York City 4½% bonds			$2268.00
Additions to the fund			63.60
Total fund			$2331.60
Balance on hand May 1, 1911	$219.12		
Interest to May 1, 1912	90.00	Unexpended	$309.12
	$309.12		$309.12

Weaver Donation

(Available for the purchase of early electrical literature)

Balance on hand May 1, 1911	$65.44	Expended	$58.75
		Unexpended	6.69
	$65.44		$65.44

Institute Appropriation Account

Appropriation for the year	$4500.00	Salary (one-third) of librarian, assistants, cataloguer and desk attendant May 1, 1911–April 30, 1912	$2700.00
		One-third running expenses of library May 1, 1911 to April 30, 1912	257.98
		Books	555.16
		Subscriptions	62.80
		Insurance	88.21
		Binding	181.42
		Miscellaneous	2.25
			$3847.82
		Unexpended balance	652.18
			$4500.00

STATISTICS OF LIBRARY MAY 1, 1912

Source	Volumes	Pamphlets	Valuation
Report of May 1, 1911	15,293	1343	$28,035.28
Purchase	181	10	604.37
Gifts and exchanges	267	2	569.50
Old material accessioned	10	20	25.00
	15,751	1375	$29,234.15

In the following table are given the figures for the total valuation of the Library property:

Books	$29,234.15
Stacks	1,761.05
Furniture, catalogues, cases, etc.	376.00
	$31,371.20

LIBRARY ATTENDANCE

	Day	Night	Total
May, 1911	833	375	1208
June, "	637	310	947
July, "	610	Closed	610
August, "	550	"	550
September, "	608	"	608
October, "	661	252	913
November, "	720	283	1003
December, "	853	287	1140
January, 1912	728	298	1026
February, "	813	273	1086
March, "	869	326	1195
April, "	719	343	1062
Total May, 1911-April, 1912	8601	2747	11,348
Total May, 1910-April, 1911	7473	3041	10,514

The income from the C. O. Mailloux Fund of $1000 has again been used to maintain the four important periodical sets which were originally presented to the library by Mr. Mailloux.

Respectfully submitted,

FREDERICK BEDELL
MORGAN BROOKS
ALBERT F. GANZ
OTIS ALLEN KENYON
SAMUEL SHELDON, *chairman.*

June 15, 1912.

An Address presented at the 29th Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June 25, 1912.

(Subject to final revision for the Transactions.)

THE RELATION OF ELECTRICAL ENGINEERING TO OTHER PROFESSIONS.

President's Address

By Gano Dunn

On the wall of a great engineering library is the legend "Engineering is the art of organizing and directing men, and of controlling the forces and materials of Nature for the benefit of the human race."

This is broad and all-embracing, but other professions will find it hard successfully to quarrel with it.

While the immediate object of engineering is a material one, engineers draw from many different channels of human energy, such as generalship, commerce, psychology, mechanics, economics, to say nothing of chemistry and physics and many others, all under an interpretation insight and method that are best described by the term scientific.

It may be asked, Why could not a similar statement of embrasure or scope apply to medicine, the law, the army and other professions?

In part it could, but it is to engineering that it applies preeminently.

The subject matter of the older professions, the things about which they busy themselves, and the objects they seek to accomplish have changed relatively little in many centuries. The means have altered but the ends persist. They are approximately the same today as they have been throughout history and tradition.

With engineering it is different. There was no such profession a hundred and fifty years ago, and if I may a little anticipate my conclusion, there will be no such profession a hundred

and fifty years hence in respect to a large part of what we now call engineering.

Such as it is, engineering is embracing an ever-growing horizon, and is including more and more of the activities of civilization.

When I say activities I refer to material ones and not to the whole of life itself. The human spirit is the greatest fact in the world, and art and literature that interpret it, the acts of our daily life and our personal relations that depend upon it, religion and the vast body of our social and political experience, that go to constitute life form undoubtedly a mass of activities, which are greater, in terms of consciousness, than the material activities which engineering can affect. In other words, the humanities which have been the same for ages can never be invaded by anything that merely rearranges our relations to the material world.

In the material world, however, which is at once the workshop and the throne, the glory and the limitation of the engineer, marvel has followed marvel and shall be followed by more marvels, for we are beginning to catch the tools' true play; beginning to see the vision of our dominion over the earth.

Whether it really is engineering to organize men, to predict the psychology of a fare-paying population, to win the endorsement of a labor union, to treble the yield of a farm by a microscope, all of which successes to-day are called engineering, depends upon the definition that we finally adopt.

It is startling to study the variety and importance of the posts filled by engineers and to note the range of what they do. From the Efficiency Engineer presenting surprises in the output of a factory where the human factor is large, or the Industrial Engineer suddenly after thousands of years showing the world how to increase greatly the lay of bricks, or the Agricultural Engineer working miracles with the soil that for ages farmers have struggled with, to the Civil Engineer establishing a kingdom and building the Panama Canal, we have instances in which the engineer is doing more and more of the worlds work.

The history of this class of men so rapidly growing in numbers, so rapidly differentiating in function is almost a romance.

The Encyclopedia Brittanica names the middle of the eighteenth century—that is, 1750—as the time before which there were only Military Engineers—who constructed "engines" of war—and it adds that at about that time there began to

arise a new class. Little did this new class realize the army it was leading down the industrial paths of time!

The "new class" has surpassed all bounds. From insignificance a hundred and fifty years ago it has increased almost incredibly in numbers and variety of specialization.

As a local indication, the Engineering Societies' Building in New York is the headquarters of fifty thousand engineers.

As another local indication, the American Institute of Electrical Engineers has in the last ten years increased six fold.

The growth in the variety of specialization has been almost as rapid as the increase in numbers.

Where there were only Military Engineers and the "new class" a hundred and fifty years ago, there are twenty-seven recognized varieties to-day.

Without mentioning all, they range from Civil through Mechanical, Electrical, Mining, Illuminating and Chemical, to Refrigerating, Industrial, Agricultural and Aeronautical. There is even a magazine with the title Human Engineering.

A large and increasing part of the capacity of our Colleges and Universities is devoted to the education of engineers.

Parts of the engineering curricula are borrowed for what used to be purely classical courses.

The metaphors of the speech of the day often have an engineering basis and—we have a McAndrews hymn.

The man in the street knows something about spark plugs, and many women understand the general principles of the telephone.

The social status of the engineer has emerged from that of a mechanic to one nearly as high as that of the clergyman, the physician or the lawyer.

Relatively recently there has been going on simultaneously with all this, however, hardly noticed, something else—a vast increase in so-called engineering work by men who are not engineers, and at the same time a large drawing off into executive, administrative, industrial, commercial, civic, educational, financial and even legal callings, of men of engineering training.

A history of segregation and disintegration seems to have begun to accompany a history of integration and building up.

For one to say to-day he is an engineer gives very little idea of what he actually does. It does not locate him in one of the twenty-seven recognized classes. It leaves it possible for the hearer to think of him as a "social engineer" or an "efficiency

engineer" should he not look like a "civil engineer;" but even if he did define himself and say he was an electrical engineer, the hearer would still not know whether he represented the last word on the loading of telephone circuits or his responsibility was to determine whether the great railroad terminals of Chicago should use a third rail or an overhead catenary.

If he should say "I am a teacher," "a physician," "a clergyman," "a lawyer," there would be a much more definite conception attaching to his answer.

There must be, therefore, in the title "engineer" something broader, something not included, or included to a lesser degree, in the titles of the other professions or occupations.

A light is shed if we examine the popular definition that engineering is "educated common sense."

Can it be that unlike "physician," "lawyer," "teacher," the term "engineer" does not describe what a man *does*, but rather *how* he does it! A method rather than an occupation! It is even so; that is, essentially and with limitations I shall refer to later.

What then is this "method" that has given the engineer his ever broadening domain and brought all kinds of men and callings to his school? He can tell you at once. Here is where he is defined and where his fellows recognize him and each other though they come from the ends of the industrial earth as to diversity of actual occupation.

The method had its birth in Greece, though it was stifled almost to death by the tremendous philosophic, humanistic and artistic energies of the Hellenes. Later it was buried in Europe under the irruption of the barbarians.

The names of Thales, dear to our profession, with his "elektron," and of Aristotle and Archimedes, stand out as having done much for it—especially Archimedes—in spite of the humanistically polarized intellectual atmosphere in which they lived and which they contributed so gloriously to create.

But the Greeks made only a start. To quote an authority, their material thinking was largely based on what has proved to be a wrong method of procedure, the introspective and conjectural rather than the inductive and experimental. They investigated Nature by studying their own minds, by considering the meanings of words, rather than by studying things and recording phenomena. But they saw much of the light with all this.

Though absoutely dead for a thousand years in Europe, "the method" was kept alive during the middle ages in Arabia, although confused with magic, alchemy and algebra.

Then came Roger Bacon, Leonardo da Vinci and Copernicus, and science as we know it began to take shape.

Aristotle had sat down in his chamber and he wrote in a book, "A body twice as heavy as another of course falls twice as fast". Galileo released simultaneously from the top of the Leaning Tower a one pound and a one hundred-pound shot and they reached the earth together, before the eyes of the assembled University of Pisa.

But "the method" was repugnant to the University, and almost to a man they believed their Aristotle, sophistically explained away what they saw, and persecuted Galileo.

Descartes, Newton, Lagrange, Laplace, Francis Bacon connote to engineers the transcendent story, unless for electrical engineers there should be added Ampere, Faraday, Henry, Helmholtz, Kelvin.

The method of doing things that makes an engineer is, therefore, the applying to practical and utilitarian ends the principles and reasoning of science. Engineering is not science, for in science there is no place for the conception of utility. Truth is her sole criterion. In the exalted language of Professor Keyser, "Not in the ground of need, not in bent and painful toil but in the deep-centered play-instinct of the world Science has her origin and root; and her spirit, which is the spirit of genius in moments of elevation, is but a sublimated form of play, the austere and lofty analogue of the kitten playing with the entangled skein or of the eaglet sporting with the mountain winds."

Engineering is Science's handmaid following after her in honor and affection, but doing the practical chores of life, concerned with the useful and the material; with costs and with expediency, and concerned with the humanities only in so far as they are an incident in some particular scheme of reality, and then objectively, if that may be said.

Her methods merely apply straight thinking to material problems for useful purposes.

Does this constitute a profession? No. Some day it will be the way almost everybody thinks instead of a body of specialists and then the difference between a doctor for instance and an engineer will be only in the things they busy themselves about; as is today the only difference between kinds of engineers.

The center of education has been shifting rapidly recently —almost as rapidly as material well being has been increasing.

The application of science to living has marked an age as distinct as the age of the climax of Art in Greece.

The "new class" has been but a pioneer in sowing the seeds of scientific rationalization in a field the value of which was only dreamed of by Archimedes and not actually recognized until, as the Encyclopedia tells us, "about the middle of the eighteenth century," when the "new class" began to arise.

And now, as to the limits within which Engineering is a method rather than an occupation.

There will always be engineers, for the methods of Science will constantly advance, and there will be needed continually, to interpret and transmit them to mankind, and to make the first applications of them to useful purposes, a class of men who, by instinct and taste, as well as by the possession of what I later shall call the dynamic component, find easier than other men—and consequently perform better—the kind of scientific thinking, observation and action that characterize engineers today.

What these men will be busy about it is hardly safe to say, although it is probable the present great divisions of engineering will be more or less preserved. It seems certain that a large mass of knowledge that now is called engineering and forms the basis of many of the engineering specializations, will become general knowledge, and will be absorbed by the community, partly as a result of the shifting of the center of education and partly through everyday familiarity, and the men possessing this knowledge will no longer be called engineers, They will be called farmers, let us say, in the case of the "Agricultural Engineer"—of course, a farmer of a very advanced kind compared to the earlier one.

But the center of education will not always continue to shift. It is shifting now only because it has so long been eccentric.

It would be a calamity for it to shift too far, resulting in a world whose sole training was applied science and the utilities.

Under such a condition, engineering and the utilities themselves would languish instead of flourishing, for there would be lacking in engineers the dynamic component.

Ample knowledge, insight, information does not make an engineer. He must first be a man. Engineering is not thought like philosophy; it is thought times action, and only when the

qualities of action are developed approximately to the same extent as the qualities of thought is an engineer at his best. Only then is his area of effect a maximum.

The qualities of action involve tastes and personality, the feelings, the will. And it is these that constitute the component or factor that makes an engineer's intellectual or rationalizing equipment dynamic—that puts it to use.

It was partly the intense appreciation of the value of the dynamic component that led the Greeks and successive centuries astray in the direction of their education and contributed to an underestimate of the importance of Science and the study of the laws of Nature.

We must not go to the equally wrong other extreme.

So far I have said but little of electrical engineering. It must be brought in if for no other purpose than to justify our title. Although the article on "Engineering" in the Brittanica occupies only six inches of one column, it concludes with the following: "The last great new branch is *electrical* engineering, which touches the older branches at so many points that it has been said that all engineers must be electricians."

If engineering is a method of doing things, and electrical engineering tends to embrace all other branches, there is an implication that electrical engineering is the latest or most highly developed form of the method—the method that is the utilitarian application of the principles of Science to the material facts of life.

Such is unquestionably the case. Born scarcely more than twenty-five years ago, the "youngest branch," Electrical Engineering had the opportunity of striking its roots into the richest of scientific soils, free from prejudices, customs or traditions. It had no entangling alliances, no political laws to retard or encumber it. The field it preempted was the Terra Nova of Engineering, the New World of Applied Science.

Under the influence of those geniuses of Science, Volta, Faraday, Ampere, Ohm, Kelvin, Helmholtz, Maxwell, Oersted, Henry, and with the metric system for its cornerstone, there developed a comprehensive structure of thought and a related scheme of units. The latter are the admiration of the world for their simplicity, their convenience, their precision and their reproducibility. The scientific method as applying to all phenomena acquired its most perfect embodiment in the electric system and its relations.

But there is a philosophical debt that we electrical engineers owe our units. They school our minds. The ability to measure with precision difficult and complicated quantities enables clear thinking on them and renders reasoning about them possible that otherwise could not be attempted. To name a thing is to know it.

The wonderful electrical units are a fluent language that gives the widest opportunity to thought. By their character they educate our faculties of definition and of relation.

They typify all quantitative thinking, not merely electrical.

They are the epitome, the last word of the great minds of our age, as to what the scientific method of thought is, in relation to the whole realm of matter and force.

Therefore although the subject matter of electrical engineering is covering a wider and wider range—so wide as to be almost incongruous, the electrical method of thinking is applicable throughout. It is spreading far beyond.

As an electrical engineer, I even find myself thinking of the crowds passing in the streets in terms of amperes and volts, and of the fluctuations of the stock market in terms of current, inductance, capacity, resistance and resonance.

That which can impose form upon our thought enables us successfully to think of any kind of thing.

The forms of thought established for electrical engineering are at once so comprehensive, so rigid, so rich in detail, and so illuminating that engineering does not bound them.

They may be called the manifestation of Science in civilization, the best representation of the scientific method at work for utilitarian ends.

They prove that the profession of Electrical Engineering not only deals with single-phase motors, storage batteries, high-tension transmissions, turbo generators, coronas, carbon transmitters and commutation, *as an occupation*, but that it also is a *way of thinking*, and as such is not an occupation, but the latest and most highly developed scientific method of solving all kinds of practical problems of matter and force, for the benefit of the human race.

A paper presented at the Pittsfield Section Meeting of the American Institute of Electrical Engineers, Pittsfield, Mass., January 18, 1912.

CENTRAL STATION ELECTRIC POWER FOR RAILROAD OPERATION

BY FREDERICK DARLINGTON

The broadest view of every engineering subject is found in its economical aspect, and our subject has its foundation in the fundamental principles of national and political economy. The solution of the problem of power supply has a particularly direct bearing on individual and national wealth producers.

Every engineering operation seeks to accomplish some useful result, which is measured by its financial worth or capacity to earn money by saving labor in doing something useful. There are no exceptions to this, but for railroad work, which will be the subject tonight, we often have to look further and deeper for the full measure of worth, than is usual in any other matters with which I am familiar.

In the manufacture of cloth for instance, the problem is simple, that is, make cloth of a desirable quality, at a minimum cost; likewise in making steel rails or bricks or paper, or any article of merchandise, there is a definite result to be obtained and the final test of different methods is the cost and value of the product, which in such instances is readily determined. There is no such simple way to judge the merits of transportation work for it is far more complex than manufacturing or other lines of production. This is seen in the great diversity of rates and classifications under which railroad accommodations are sold. In freight business, for example, there are different rates for long hauls and for short hauls, for car loads and for part car loads and various classifications almost without limit. This diversity has not, as many people suppose, resulted primarily from a desire on the part of railroads to "charge what the traffic

will bear," but rather from necessity caused by differences in transportation costs, combined with differences in the value of services rendered. It is not necessary to enlarge upon this for we all know it would be fatal to the interests of both buyers and sellers of transportation, to attempt to make a uniform rate for all freight transportation on a ton-mile basis, or on a uniform basis of distance hauled, or on any direct measure of transportation. An equitable rate for carrying a ton of wheat from Chicago to New York City has very little relation to an equitable rate for carrying a ton of wheat twenty miles from a farm to a grain elevator; likewise, there is very little relation between the cost per ton of transporting a car load of wheat and the cost on a single ton in a part car load lot, and short hauls and part car load lots may be quite as important in the aggregate as long hauls. What I want to bring out is not the value of the work done by the railroads, immense and necessary as it is, but rather to point out the need for still more and different railroad facilities, and to show that the use of electric power from central station plants will benefit railroads and at the same time benefit all other operations requiring power.

There is a wide field for improvement in railroad service that can be best accomplished with electric power, especially for local transportation. The statement has been made that the money expended in wagon hauling freight to and from freight depots of one of the largest railroad systems in New England, is greater than the gross receipts of the railroad from its freight business, and I am inclined to believe that this will apply to other American railroads. It is certain that the cost of wagon hauling freight to and from railroads, is a heavy part of freight transportation. Also in passenger service the collection and distribution of passengers to and from railroad depots, is a matter of large cost and has an important bearing on travel. This is evidenced by the work of electric interurban trolley roads, the favorite field of which is in the territory tributary to steam railroads, where they have in many places greatly facilitated the local collection and distribution of traffic. I will not enlarge upon this for it is well understood.

In comparing steam and electric power for railroads, the comparison should not be based on the relative cost of operating certain trains by steam and by electric motive power, but the comparison should be made between the best use of steam power considering the cost and value of the service rendered, compared with the best use of electric power, considering the cost and value

of electric service. It follows from the wide difference in the nature of the two kinds of power, that the train weights, schedules etc., and even the locations that are best for railroads employing steam power, will not always be best for electric power.

As far as distribution of power is concerned, independent of whether it is for railroads or for other purposes, it is demonstrated that wherever a large number of small powers are to be supplied in a limited territory it is more economical to distribute it by electricity than by any other known method. An example is seen in the case of textile mills, where power from steam engines or water powers was formerly generated at each mill and conveyed to various rooms and machines by series of shafts and belts. This plan has been widely superseded with electric drive whereby electricity is generated in a central plant supplying numerous mills and is used to operate motors for driving small groups of machines in each mill, or even for driving a separate motor for each machine. Likewise, in railroad work, electric motive power enables a profitable service to be rendered, with greatly subdivided motive power suitable for light and frequent trains that if operated by steam power would be too costly to be profitable in such small units. So it has been in every field where electric power has been extensively applied. The most important result has not been a cheapening of work that was previously accomplished by other means, but more and better work has been accomplished, and so it will be with the use of electricity on railroads and this betterment will not be confined to railroading, because there is an interdependence in electric power operations, whereby any extension of electric lines and increased use of electric power for any purpose, leads to development of more and better electric power for all other purposes. How this must always result can be predicted by using a little justifiable imagination to clear the point of view of natural bias in favor of present conditions and methods that have gradually become unfavorable for present needs.

Custom and habit often leads to the continued use of apparatus and methods for work that could be better met by new means. To appreciate this, imagine that a wholly new country, that is destined by natural resources to become rich and prosperous, is to be opened up, settled and developed, and that some empire builder with a master hand and complete foresight could furnish the transportation and power facilities of the country. By means of electricity and the railroads, he could direct the development of the country. First of all by building railroads with

electric motive power, he would at once provide the means of transportation that is always adopted where the population is sufficiently dense. Following such lines of convenient transportation and power, population centers and settlements will naturally locate on the railroads with transmission lines along the roads, these various centers are tied together, forming the most efficient power system. If a country is to have a density of population and prosperity that would pay for transportation by electric roads, then the railroads should unquestionably be provided with transmission lines connecting the cities and these same transmission lines carrying electric power along the railroads, make the most economical means for distributing power for every purpose, and all the street cars, house lighting circuits, shops and factories along the railroad, would naturally derive their power from these lines, and towns and manufacturing centers are always attracted by convenient power, as well as by good transportation conveniences. Then again, a diversified and extended use of electric power within any area, increases the size of the power plants employed therein and accordingly reduces the cost of each unit of power generated.

A manager acting for a central power plant desiring to sell power to a city electric railroad system, recently put the matter as follows: To the banker president of the railroad, who has a reputation of being difficult to convince in any such matters as sacrificing or setting aside part of his property, the manager said "Do you want to make a dollar?" To which, after the way of bankers, he answered, "Yes." Then the manager asked him if he "Would share the dollar with someone else who helped make it," to which he answered, "Yes, if he could not make it all himself." Then said the manager, "I will sell you power for your railroad at less than it costs you to make it, and even so, I can make a profit on it, for you are making it in 1000- and 2000-kw. units and I am making it in 5000- and 6000-kw. units, and, therefore, at less cost than you are; but besides making it in larger quantities than you are, I am serving a great variety of companies and secure a more even and steady load than you do since you are making power for only one kind of service, namely, to operate an electric railroad; but in addition to these reasons, I want your business, because with your load added to my present load I can generate power in 8000- and 10,000-kw. units, and still further reduce my kilowatt-hour cost."

It is not a matter of opinion but of accomplishment that available central station power is a valuable asset to every

prosperous settlement, just as are railroads and telegraph and telephone systems. As power machinery and methods of work that are not now adapted to the electric plant, are becoming obsolete or wearing out they are being supplanted by electric machinery and electricity is being installed in new works where foresight is exercised to realize the maximum benefit by centralization and unification of power.

Much that was sought by railroads long before electric motive power was available for their needs is now accomplished with electricity. Years ago Wellington in his standard book entitled "Railroad Location"—a book by the way, that deserves a much more comprehensive title—pointed out that "In the sale of transportation the price that the consumer is able and willing to pay, is greatly affected by trifling differences of convenience." He emphasizes the importance of convenient local transportation facilities and says that "The loss to the railroad due to not supplying the best facilities might be borne if it meant simply a reduction of transportation tax upon the traveler or the shipper of freight." (In other words less money paid to the railroad), but he asks, "How stands it with the traveler or shipper? They save indeed the two or three cents per mile, which the railway loses, but they have to pay the entire cost of cartage on their freight and pay for their own conveyance besides suffering the annoyance and inconvenience, which they estimate at a good round sum." He says, "From poor transportation facilities, the loss is threefold: The cost to the public is greater. The receipts to the railroad are less. The traffic is decreased in volume." To quote still from Wellington, "This means from the point of view of political economy, and as a plain statement of fact, which would appear in census statistics, that the capital of the country and the world is less than it otherwise would be."

We can now add to Wellington's list of losses and state that poor transportation when resulting from failure of railroads to employ electric power under conditions favorable to its use will cause a fourfold loss including the three losses enumerated and adding a fourth represented by the added cost of power both for railroad working and for industrial uses, and in the fourth instance, as in the three enumerated by Wellington, this means from the point of view of political economy, a loss to all—to the railroads and to the public alike.

While it has been one of the works of electric railroads to produce added values with better transportation facilities, it is not my intention to reiterate arguments for better local service

with electric power as a means of increasing values. It is rather the purpose to accept the evidence of interurban railroads that electric power is advantageous for light and frequent train service, and from this premise to examine the conditions for its further application.

The general statements thus far made concerning central power supply and railroad operation, are all capable of verification by examining specific conditions, but as I indicated at the commencement of this paper a complete analysis to apply to all conditions is most complex. It will be possible for me to give here only a few results based on actual operations which may be used by those interested as a basis to compute what economy centralization and unification of power supply will secure at other places.

The figures given below are for the cost of producing electric power in steam plants carrying railroad loads under conditions that are widely prevailing in the United States. These figures are not exact costs taken from any particular power plant, but are average costs worked out from actual results in several steam plants on heavy railroad and other work, so shown as to permit easy analysis for varying conditions of load and for different fuel costs, etc.

	Total cost per year	Cost per year per kw. of plant capacity	Per kw-hr.
Operating labor	$52,500	$2.10	0.100
Operating materials (exclusive of fuel)	15,000	0.60	0.025
Labor for maintenance of plant	15,000	0.60	0.025
Material for maintenance of plant	17,500	0.70	0.030
Total cost of power plant, operation and maintenance, exclusive of coal per yr.	$100,000	$4.00	0.180
Add the cost of coal at $1 per ton for coal of 13,500 B.t.u. per pound	82,500	3.30	0.15
Note:—The fuel cost will increase as the cost per ton increases or the quality falls off			
Other expenses pertaining to power plant operation, such as administration, legal and general expenses	10,500	0.42	0.02
	$193,000	$7.72	0.35
Add for fixed charges on the cost of power plant	225,000	9.00	0.41
Total cost of power per yr. with coal at $1 per ton and a load factor 25 per cent	$418,000	$16.72	0.76

The figures given are the cost, including fixed charges, of producing power in a 25,000-kw. steam turbine plant, containing five main units of 5000-kw. nominal capacity each, but capable of carrying 50 per cent overload or more in emergencies.

The yearly production of power is assumed at 55,000,000 kw-hr. or a load factor of 25 per cent on a maximum load of 25,000 kw. which is the total nominal capacity of the five generators. It is equivalent to an average operation of all of the generators for 2200 hours per year at their rated capacity.

Such is the cost of electric power generation by steam for heavy railroad operation and general central station service.

There are two factors in the foregoing costs which are liable to maximum variations, viz., the cost of fuel and the average load on the plant, or as it is called, the load factor. The assumed maximum load of 25,000 kw. could easily be carried on four ordinary 5000-kw. nominal capacity steam turbine generators, and leave one spare unit in a five-unit station. At 25 per cent load factor as assumed above (25,000 kw. maximum load and 55,000,000 kw-hr. per year), the result in thermal efficiency would be about 8.4 per cent. It is difficult to determine from actual results just what the thermal efficiency would be at other load factors, but as it is sometimes necessary to know this as a basis for arriving at the fuel costs under varying load conditions, the following approximate figures are given for these variations. The coal is assumed to contain 13,500 B.t.u. per lb.

Yearly load factor (ratio of maximum load to average output)	Average operation per yr. hours	Thermal efficiency of plant	Cost of coal per kw-hr. at $1.00 per short ton
10 per cent.	876	6.5 per cent.	0.20 cent
20 " "	1752	7.8 " "	0.16 "
25 " "	2190	8.4 " "	0.15 "
30 " "	2628	9 " "	0.14 "
40 " "	3500	9.8 " "	0.13 "
45 " "	3940	10.1 " "	0.125 "

It would be difficult to demonstrate in detail the economies that can be derived from combination of mixed power service from the above plant compared with power for only one industry like railroads, and an attempt at it would lead back to the same generalities that I have already stated, but analysis of the

schedules of costs and thermal efficiencies for a 25,000-kw. plant, working at 25 per cent load factor, proves the broad assertion that in power generation large stations carrying mixed loads afford the maximum economies. Take for example, the cost of general expenses and of fixed charges and of power station labor and material, exclusive of coal. These things are little affected by the load factor, but even in so large a station as 25,000 kw. they amount to $13.42 per kilowatt per year, out of a total cost of power of $16.72 per kilowatt per year, with good coal at $1.00 per ton, or $20.02 with coal at $2.00 per ton, etc. Furthermore, even the fuel cost per unit of power generated will ordinarily be less in mixed service plants than on plants for railroad work only, since the former generally work at better load factors than the latter. The better load factor comes from serving a diversity of operations. Also with more operations the plant will be larger and for this reason as well it naturally has a better load factor and all unit costs are correspondingly less.

There are other important advantages from centralization of power in large power plants, which will have important bearing on the future of central station business, for industrial and for railroad power. One of these has to do with obsolescence and its importance in this connection does not always immediately receive the attention that it deserves. Another is the utilization of off-peak or secondary power, which so far has been very little realized but which will increase in importance.

Obsolescence has long been the bugbear of electric companies that are striving to earn dividends, and centralization of power seems to be their best means of salvation. We all know that electric companies that were started fifteen or more years ago, whether they were for lighting or for railroads, or for whatever purpose, have found a large part of the cost of conducting their business has been due to the failure of apparatus to meet growing demands not so much because it was worn out as because it became obsolete, when increasing business required larger powers and improved machinery.

Good serviceable power plants became obsolete because they could not do the increasing work of later years, and were discarded because the use of power increased. Centralized power plants meet changing conditions because they are built for larger service and constructed on a unit plan that can be economically extended to meet growing demands.

The utilization of off-peak power will be promoted by the concentration at central points of large amounts of off-peak power, which can be more readily utilized as second class power than the same amount of off-peak power if scattered through a number of small generating plants.

There are several very promising methods in prospect for utilizing off-peak or secondary power when it is concentrated in large blocks, but it is not within the scope of this paper to go into a discussion of them.

Next turn to the power transmission side of the problem. In this the results in favor of large mixed operations are even more striking than in power generation. It is a difficult subject to generalize on, but briefly, suppose that a central plant is located at a favorable point at a coal mine or a water power, and it is desired to transmit power from the plant. It often pays to run 100 miles of transmission line to pick up a large load, whereas for a small load, the cost of 10 miles of transmission may easily be too great. It follows that if the aggregate amount of power surrounding the power center is not large, it will not pay to go far for it, and the economical distribution area may be restricted to a radius of 10 miles or less. But on the other hand, if the aggregate is large, long distance transmission will pay and the combination of large amounts of power per mile of transmission on long transmission lines, covering large areas, gives a big connected central station load. In this lies one of the great advantages in favor of including railroad roads on central plants, viz., where the amount of power and lighting scattered through a territory for manufacturing purposes is not sufficient to make it economical to install electric transmission for this alone and where the railroad business is not sufficient to pay to transmit for railroad power alone, transmission for the combined loads will often be highly profitable.

There is a well-known power transmission company that affords an excellent example of the advantage of combining as much power as possible in a given territory. Its business aggregates something like 60,000 h.p., connected on several hundred miles of transmission lines, and the yearly cost of transmission including all fixed charges and operation and maintenance of the transmission system, amounts to about $12.00 per h.p. per year, based on its peak load of 50,000 h.p. Its load is industrial power and lighting with a few street railways. In the same territory there is a total consumption of power exclusive of

steam railroads approximately 225,000 h.p. which if all served from a single central power plant would produce a maximum load of probably 150,000 to 175,000 h.p., but for various reasons one of which is the use of exhaust steam for heating buildings, factories, etc., the maximum load that it would be profitable to serve from the central plant would probably give peaks of only about 100,000 to 120,000 h.p., exclusive of steam railroad operation. The yearly cost of power transmission including all fixed charges on transmission lines, for serving 100,000 h.p. in this territory instead of 50,000 h.p. maximum as now served, is estimated at $730,000 total or $7.30 per h.p. per year as compared with $12.00 per h.p., which is the cost of power transmission and distribution for 50,000 h.p. only.

An examination of the steam railroad traffic in the same territory indicates that if all of the railroads used electric motive power exclusively, the railroad load would require a generating capacity of between 200,000 and 300,000 h.p., and if only the railroad lines carrying heavy traffic and frequent train service were electrified in the territory, the maximum load if served from a central station would be somewhere between 150,000 and 200,000 h.p., and that the yearly load factor of this railroad load, including freight and switching and passenger service, would be between 40 and 50 per cent. It is clear that if this load were added to the industrial and lighting load, it would greatly facilitate and cheapen the unit cost of distributing power from the central station.

In conclusion, I want to review briefly what the substitution of electric motive power for steam on existing railroads should include. It is not enough to say that it would require the construction of central station generating plants, of transmission and distribution lines, generally following the railroads and of electric locomotives to replace steam. These would all have to be provided, of course, but that is not nearly all that should be done. Unless we look beyond such facts we cannot even appreciate the problem before us, much less solve it. When the railroads are paralleled by transmission lines over which central stations supply electric power for their operations, then the country traversed by the railroads will be in electric power zones, where power for any purpose may be taken from the lines along each railroad right of way and these lines will connect large central stations together, so that transmission lines will network the country as railroads now do and will connect

important centers for power, as railroads do for transportation. Into this net work of transmission circuits central electric plants will pump energy that can be drawn off in just the right amount to supply the needs of each point included in the network.

When this is carried out, the distribution of power, which is the greatest problem in the way of almost universal use of central station electric power, will be overcome with the resulting economy in generation as well as in distribution, since the most economical conditions for both generation and distribution are where large amounts of power are supplied at the best load factor attainable, which results when the largest number of operations are supplied from a single system. Thus there are many places where railroad electrification will be profitable as outlined, where it would not pay to build transmission lines for the railroad load alone or for the industrial power and lighting without the railroad load.

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ECONOMIES IN RAILWAY OPERATION

BY F. E. WYNNE

Never before in the history of modern industrialism has there been such a stupendous effort made by every one for high efficiency as at the present time. It is the keynote of every convention; the proceedings of the Institute and other engineering societies are full of it; magazines and daily papers are devoting a great deal of space to the subject.

Under such conditions it is natural that the pendulum in railway operation, which has until recently been swinging far upon the side of safety and reliability at any cost, started to swing towards the side of reduction in cost, at the price, as some engineers think, of both safety and reliability. When this happens, an extreme is likely to be reached that may show a reduction in cost of some items that have been in the lime light but will show an increase in other items affected thereby that will far outweigh the reduction. The way to avoid such an undesirable condition of affairs is to carefully analyze every point and study it from all sides before making a change from practise that is giving good results. In other words, the old maxim, " Be sure you are right, then go ahead," applies here with special force.

Probably nowhere has this search for efficiency been more active than in the electric railway field. In the first place every part of the equipment has been studied with the greatest care to increase its life and reliability and decrease the cost of maintenance. This has resulted in the present magnificent equipments that are found on all up-to-date roads. Car bodies, trucks, wheels, control and motors have all been improved to an extent undreamed of a few years ago. Not only has there been

a great increase in reliability—which is always one of the greatest assets a road can have—but the cost of inspection and maintenance has been reduced to a degree that makes it cheaper to scrap old equipments than to operate them.

Since the life of wearing parts has been increased to an extent that but little return may be expected from further endeavors along that line, the busy minds of engineers all over the country have been turned towards other means of reducing cost of operation and have naturally rested on the cost of power. This is usually one of the larger items in the cost of operation and offers a fruitful field for investigation. A great many engineers have figured out the amount it costs to carry around the dead weight of a car and have given figures varying from 3 to 10 cents per pound per year. These figures must of course depend on the mileage, the cost of power per kw-hr. at the car, and the kind of service. For instance, the mileage of cars may vary from 15,000 to 90,000 miles per annum. Power may cost in one place 0.4 cent per kw-hour at the switchboard, and in another place may run twice that amount. Then the cost of getting a kw-hour from the power house to the car varies widely. Finally, the conditions of service may vary so much as to take anywhere from 40 to 150 watt-hours per ton-mile at the car. A road which averages 50,000 miles per car per annum, consuming 100 watt-hours per ten-mile at the car and whose power costs 1.5 cents per kw-hour at the car, will pay $3\frac{3}{4}$ cents per pound per annum for power.

$$\frac{50000 \times 0.100 \times 1.5}{2000} = 3\tfrac{3}{4}$$

But whatever the actual cost may be, it has put the matter before the operating people in such an attractive way, that many of them have been bending every energy to reducing weight, thinking that every pound reduced, no matter how reduced, will result in an immediate saving of 5 cents per pound per annum. Some even go so far as to say that every pound removed from the dead weight of a car is worth 75 cents to them—off the car. This is the kind of talk that must be accepted with a good deal of reservation. It is no doubt true that if the cost of operation per ton-mile remains the same with the lighter weight cars and equipments, the saving will be made. The danger is that in reducing the weight, conditions may be altered so much as to make the cost of operation more than before. The cost of

inspection and maintenance may be increased on account of the necessity for more frequent renewals of wearing parts. It is intended to discuss in this paper some of the proposed means for saving power on electric railroads and to clear up, if possible, some of the misunderstandings that exist at the present time.

I. Reduction of Weight

In the development of the electric railways, the evolution of cars and equipments from the old horse cars to the modern double truck city cars and the high speed interurban cars has been attended by much grief and loss. The development was so rapid that the only method possible to pursue was to build the car and equip it, using the best judgment available in proportioning the parts. Where parts broke in service, they were usually strengthened by increasing weight and section, regardless of the actual cause of the break which might have been in something entirely different. This of course resulted in designs which were unnecessarily heavy. It is the part of good designers and conservative engineers to re-design them, distributing material where necessary for strength and cutting out as much unnecessary material as possible. It is astonishing what results have already been obtained in this line, and the end is not yet. The use of high-grade materials and pressed steel shapes with new types especially fitted for them will still further reduce weights of car bodies and trucks, and now the question has been put squarely up to the electrical manufacturers to reduce the weight of the motors and control apparatus.

Motors. The weight of motors may be reduced as follows:

1. By cutting out all useless weight; in other words, by very careful designing.

2. By the use of high grades of metal to give the necessary mechanical strength with smaller sections.

3. By the use of higher grades of insulation which will allow operation at higher temperatures and thus permit the use of smaller motors.

4. By the use of forced ventilation, thus enabling the motor to carry larger continuous loads with safe rise in temperature.

5. By increasing the armature speeds which thus gives a greater output to a given size of motor.

1. *Improved Design*. The first method of cutting the weight, that is, by eliminating all useless weight, is a quite obvious one, and has been followed to a greater or less extent for years. It

is now being worked to the limit, and it is safe to say that all motors which are designed hereafter will have a minimum of useless weight in them.

2. *High Grade Metals.* Higher grades of material have also been used more or less, and there are now very few motors that have cast iron in them where weight would be saved by the use of malleable iron or of steel. Heat-treated steel is also used in some cases for shafts, and will probably be used increasingly hereafter. At present, however, its use on standard apparatus is attended with danger and expense, since the methods of heat-treating steel are not generally well-known, and, where special materials are used, it always results in more or less dissatisfaction in making repairs. In any case, the reduction of weight in shafts that is possible by this method is very limited since the reduction in diameter reduces the stiffness in the shaft very rapidly, and even if the shaft is of the high grade material, it is not safe to permit the deflection.

Great improvements have been made in steel castings in late years. This permits the use of thinner sections than it has been possible to cast theretofore. This will reduce the useless material.

3. *High Grade Insulation.* A certain amount of increase in capacity from a given size of motor may be obtained by the use of heat-resisting insulation, and it has been common practise for years to make use of such insulation in the larger sizes of motors and in field coils for smaller motors, it being common practise to use mica insulation for armatures and asbestos insulated copper strap for field coils. It is very difficult to increase the output of machines so insulated more than has been obtained for years. Small wire-wound armatures have been wound in many cases with the wire insulated by preparations of asbestos which have increased the safe temperature limit very materially in such machines. Such insulation, however, must be handled with much greater care than ordinary coils insulated with cotton or similar fabrics, as the asbestos is very weak mechanically, and armatures are more liable to short-circuit. The net gain capacity by using high-grade insulation is somewhat reduced because better insulating materials are poorer heat conductors and a given load produces higher motor temperature than with poorer insulation. The limit to the temperature in motors at present is the melting point of tin solder and we believe that very little increase in temperature above the present limits will be possible until a soldering material with higher melting point is produced.

Tin melts at a temperature of about 225 deg. cent. This seems like a good margin to give a motor which is supposed to operate around 75 to 100 deg. cent.; as a matter of fact, the sudden heavy loads on motors which do not last long enough to heat up the entire armatures will last long enough to melt the solder out or at least soften it to a point where it is thrown out by centrifugal action. This probably will be much more frequent where the motors are normally operated at higher temperatures than at present. Therefore, we feel that this offers no great increase in capacity. At least any increase in capacity thus produced will be obtained simultaneously with the lower efficiency of motor, since in most cases a small motor operated at heavy overloads and high temperatures will have a lower efficiency than the size larger motor operated in the same service. Thus part of the saving which is effected by the use of a little lighter weight motor is lost in the decreased efficiency of the motor.

4. *Forced Ventilation.* The fourth method of increasing the output, namely by forced ventilation, has been in use for some years, and is quite effective. It is surprising what an effect a small amount of air circulating through the motor will have on the temperature, and capacity. It has the effect of increasing the continuous capacity of motors, which ordinarily is not more than 45 to 50 per cent of the one-hour current rating, to 65 to 80 per cent of the hour rating. In locomotives air is forced through the motors by motor driven blowers in the cab. These blowers take their air chiefly from the outside of the cab through louvres in the side wall of the cab. The air is taken at a sufficient distance above the road-bed, so that very little dust is blown into the motors, consequently, they remain quite clean inside.

The single-phase locomotives for the New York, New Haven & Hartford Railway Co. were probably the first machines that employed the use of forced ventilation on a large scale. This system is used on all of the single-phase locomotives and some of the motor cars now in use, not only on the New Haven System, but on the Spokane & Inland Empire Railway, St. Clair Tunnel, Rock Island & Southern Railroad, and others. The later locomotives on the New York, New Haven & Hartford Railroads, the first of which has been in operation for two years, are also supplied with fans on the rear end of the armature, which are so arranged as to draw air through longitudinal holes in the armature core, thus greatly increasing the effectiveness of the air which is forced in from the outside. In cases where these

motors are extended through the floor of the cab into the interior it is usual to circulate the air through the motor by means of the fan on the motor itself, and the external blower is unnecessary. Where the motor is below the floor and exposed to all the dust and dirt, it is undesirable to permit the air to be drawn into the motor, as it will draw with it too much dirt and will invariably deposit it on the inside of the motor. A great deal may be accomplished by the use of fans on the armature with openings through the armature. This establishes a circulation of air inside of the motor, thus bringing the air in contact with the outside of the motor frame which can radiate it. The radiating surface of the motor may be increased by the use of ribs cast on the outside of the frame as is done in air compressors and such things as automobile radiators. The greater the external surface of the motor, the greater the radiating surface will be, and consequently the lower the temperature of the motor.

5. *High Armature Speed.* Increasing the armature speed is permissible where it can be done without sacrificing economy of operation. Cars which are operated at high speeds may have high-speed motors on them, the limit to the speed being simply mechanical considerations. It is governed entirely by the maximum speed at which the cars are to be operated. This method has also been in use for years, as it has been common practise to have two or more motors of different capacity but approximately the same weight. A certain frame is adapted to give a certain torque at the armature shaft. This will be usually somewhat greater with a low speed winding than with a high speed winding, but roughly speaking, it is a constant, and the horse power rating of the motor will consequently be increased as the rate speed is increased. Thus a motor which at ordinary speeds would develop 30 h.p. may, by increasing the speed about 35 per cent, be able to develop 40 h.p. Such high-speed motors are very satisfactory for high-speed service. Where low schedules are required, high armature speed has the same effect on the efficiency of operation as the use of a small gear reduction on a low-speed motor. It is a fact which has been well-known for years, and is now almost universally accepted, that an equipment with a high-speed gear ratio on city cars will use a great deal more power than the same equipment would take if supplied with the maximum gear reduction. The recognition of this fact has resulted in a wholesale change in gear ratios on the cars in many of our large cities, notably Brooklyn, Chicago,

Baltimore and Pittsburgh. It will in most cases be found that for ordinary city service a motor operating at a full load armature speed between 450 and 550 rev. per min., when supplied with its maximum gear reduction, will give the greatest economy in operation. Motors operating at 600 to 700 rev. per min., if supplied with maximum gear reduction, will require more power on account of greater rheostatic losses in starting. Consequently, it is very essential that care be taken in selecting motors, not simply to pick the motor having the lightest weight, but to select one which has the correct speed and torque characteristics. It will be found that far more can be saved by gearing the motor for the most economical speed then can possibly be saved by any reduction in the weight. It is not at all uncommon to save 15 per cent or 20 per cent in power by a change in gear ratio, while the weight of the motors alone cannot be changed by increasing the speed so as to affect the total car weight more than five per cent. Further, any increase in armature speed above the economical speed will not reduce the weight of motor required for a given service, for the root-mean-square current of the high-speed motor will be greater than that of the low-speed motor in proportion to the increase of speed which is proportional to the increase in capacity. Therefore, a given service will produce equal heating in motors of the same weight but different speeds with the same gear ratio.

Control. The weight of control apparatus may be reduced as follows:

1. By improved design of parts.
2. By more efficient arrangement of switches.
3. By more efficient use of resistance.
4. Better location of apparatus on the car.

1. *Improved Design.* As in motors, better design will eliminate all useless weight from control apparatus. Here also high grade material may be employed to advantage and it is probable that the greatest reduction in weight will be effected by the use of structural and sheet steels in places where cast iron is used at present.

2. *Improved Arrangement.* Where a number of similar operations are to be performed by a number of similar units of apparatus there is the possibility of accomplishing the same result with widely different numbers of units. Reducing the number of units required to a minimum is a matter of development and frequently there is a chance that some new combinations of units

may be discovered which will employ fewer units than required by present standards and so reduce the weight of the control equipment. An example of this occurred in connection with the control for high-voltage direct-current motors, when a new scheme of connections was devised so that only 13 unit switches were needed to perform the same functions for which 18 switches had previously been used. Incidentally with the smaller number of switches more breaks in series were obtained, resulting in a better as well as lighter control.

3. *Better Use of Resistance.* In modern equipments, the weight of the resistance may be roughly from 10 per cent to 20 per cent of the total weight of all the control apparatus. By using the same sections of resistance in different combinations for different controller notches, not only may the weight of resistance be reduced, but the number of switches employed may be decreased and the main wiring lessened.

4. *Better Location of Apparatus.* The amount of wiring may be reduced to a minimum by carefully arranging the apparatus under a car. It is often also possible to cut down the weight of hangers required from that which at first seems necessary. More could be accomplished in this respect by closer cooperation between the car builders and electrical manufacturers.

Two-Motor Equipments. In many of the large electric railways and steam railroad electrifications, the advantages of two-motor equipments in place of four-motor equipments have long been appreciated. Where only half of the wheels are available for adhesion, of course the conditions of grade and climate must be such that from 60 per cent to 75 per cent of the total car weight will permit developing sufficient traction for all the requirements of the service. Where the full weight of the car is required for adhesion, the two axles of a truck may be connected by side rods. Experiments have been made in this line with more or less success and complete success depends only on the design of truck including side-rods and method of hanging and applying brakes.

With two motors, the total equipment weight per horse power is from seven per cent to 30 per cent less than with quadruple equipments, because the two motors weigh less than the four, the control apparatus is lighter and less wiring is required. A further gain may be made in the trucks since the weight of two trucks *may* be less and *need* be no greater for two large motors than for four small ones.

In addition to having a higher weight efficiency, two-motor equipments have higher electrical efficiency and reduced first cost and cost of maintenance.

II. Proper Gearing and Armature Speed

*" The selection of improper gear ratios for railway motor equipments has alone caused a loss of hundreds of thousands of dollars to the operating and manufacturing companies in this country. Motors have been overloaded and burned out by the thousands. Fifty horse power motors have been used where forty horse power motors would have done equally well if properly geared. Power houses and substations have been overloaded, have had their load factor greatly decreased and the line loss has been greatly increased, simply because the motors on the cars have been geared for too high speeds. Few people who have not made a special study of the subject realize its importance, and at the present time, in spite of the campaign which has been waged against it by the manufacturing companies and a few enlightened engineers, there are still a good many motors in service which are so geared as to result in a continual loss to the operating company. The large companies have been realizing more and more in recent years the disadvantages of high speed gearing and some of them are now making wholesale changes in their gearing, reducing the maximum speeds and making savings of five to twelve per cent in power consumption, besides greatly reducing the temperature of the motors."

†" Probably the most common error in gearing is to gear for high speed where the service is such that the stops are frequent and there is no opportunity to run at high speed. The typical cycle for such runs is rapid acceleration, short coast and rapid braking. Consequently the acceleration and the run, to be accomplished most efficiently, would be made with a low-speed gear. That which is so self-evident in this case holds good in lesser degree with longer runs. Therefore, having selected a motor with sufficient capacity for a given service, the best gear ratio to use is the lowest speed gear which will give the required schedule speed with a reasonable margin for making up lost time."

Probably five to ten per cent of all the power used for propelling electric cars and trains could be saved by correct gearing.

* N. W. Storer in *Electric Journal*, Vol. V. p. 510.

†F. E. Wynne in *Electric Journal*, Vol. III, p. 379.

The maximum gear reduction varies from 3.5:1 to 5:1, depending upon the power of the motor. The armature speed at the 500-volt rating of the motor varies from 500 to 650 rev. per min. Therefore, with maximum reduction and minimum wheel diameter, the car speed at full load of the motors varies between about 10 and 18 miles per hour. Even motors of the same power are built for such speeds that with the same gearing, the car speeds differ by as much as 25 per cent. The opportunity for incorrect motor application, particularly where stops are frequent, is therefore apparent.

City Service. By city service we mean the service in the larger cities where stops average seven or more per mile and are fairly evenly distributed. In such service there is very little or no running at full speed. The essentials for maintaining the

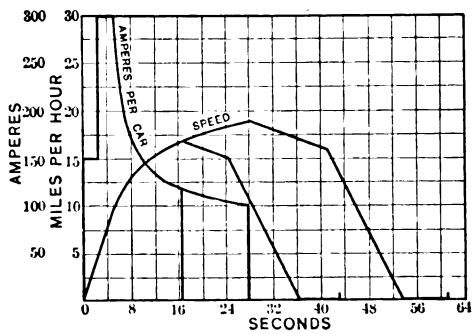


FIG. 1.

schedule are rapid acceleration and braking. In most cases there is no difficulty in keeping cars on time with the motors geared with the maximum reduction. Under such conditions a motor of low rev. per min. with the same gear reduction, will do either one or two things; it will give the same rate of acceleration with less current or with the same current it will give a higher rate of acceleration than the motor of higher rev. per min. Both of these features tend to reduce the power consumed.

As an illustration compare the shorter runs in Figs. 1 and 2. In each case train, grade and curve resistance has been taken at 22 lb. per ton. The slow-speed motor of Fig. 2 takes the same accelerating current as the high-speed motor of Fig. 1. Because of the quicker start with the low speed motor, the heavy current does not last so long, the same amount of coasting is obtained, and

the brakes are applied at a lower speed. The gain in power consumption in favor of the slow speed motor is 10.9 per cent. Part of this saving is the result of lower rheostatic losses and the balance is due to the smaller amount of stored energy wasted in the braking process. It should be noted that the gain of 10.9 per cent is in total power consumed and is in spite of the extra weight of car with the slow-speed motor. It is further worthy of note that the heating of the high-speed motor is the greater.

These curves will also serve to illustrate the effect of gear ratio. The high-speed motor corresponds to the slow-speed motor with a 4.43:1 gear reduction. However, in this instance the car weights should be the same so that the difference in favor of the slow speed gearing is even a little greater than the 13.8 per cent saving indicated by the watt-hour per ton-mile values of the figures.

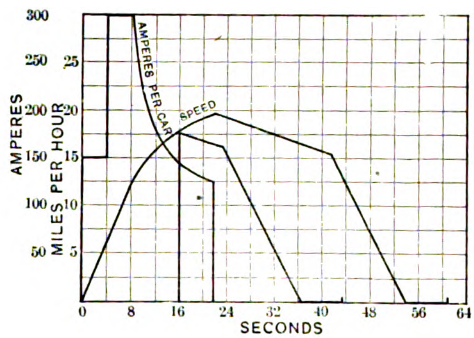


FIG. 2.

The motor speeds used are within the limits of commercial apparatus and the gearing is within the limits found on the same motors in the same service, so that actual service conditions are represented.

The argument most frequently heard against the adoption of slow armature speed and high gear ratios for city service is that the car speed will be so slow that the running time will be greater. Let us examine this contention and see of how much value it really is. Figs. 1 and 2 show that the two motors make the schedule equally well. The higher acceleration is obtained with the slow-speed motor without subjecting the equipment to any heavier current. The amount of coasting is practically the same, so that if the runs were made without any coast, the times would be the same. The high speed motor is

already slightly overworked, so there is no hope of making a faster schedule by forcing its rate of acceleration up to the value which is safe with the slow-speed motor. Neither can the high-speed motor take advantage of more rapid braking to increase the schedule speed. However, since the slow-speed motor is not yet worked up to its full capacity, it can use faster braking to a certain extent without being overloaded.

The figures given above show the saving in power at the car. This is further augumented by the accompanying reduction in losses throughout the system from the cars to the coal pile on account of the reduction in the duration of peaks and the improved load factor with slow speed motors. Therefore the figures given are conservative. The assumption of equal gear reduction

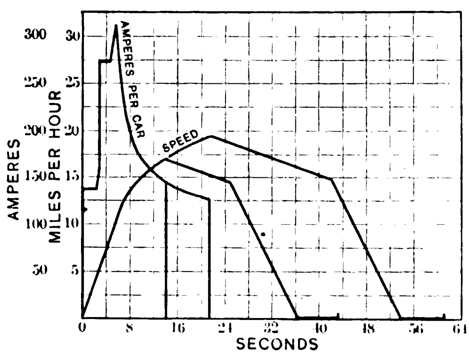


Fig. 3.

is fair because the maximum gearing is fixed by the power of the motors and the clearance between gear case and track.

Now consider whether the saving due to less weight will make up for the loss in power consumption. If the car under consideration makes 30,000 miles annually, the car with light high speed motors at 4.21 kw-hr. per car-mile will consume 126,300 kw-hr. annually while the car with slow speed motors will consume 112,500 kw-hr. The annual saving is 13,800 kw-hr. At one cent per kw-hr. this amounts to $138.00. At five cents per pound per year, the high speed motor car would save $100.00 annually. The net saving is $38.00 annually in favor of the slow-speed motor. The actual difference is more than this because part of the saving of five cents per pound annually is based on reduced power consumption with the high-speed motor. We have shown that this basis is incorrect.

If the heavier car consumed the same energy per ton-mile (145 watt-hours) as the lighter car, the latter would save in energy 4350 kw-hr. annually. Hence $43.50 of the $100.00 annual saving credited to the light motor above is not really obtained and the actual net saving for the slow speed motor is $81.50 per year.

Many railway systems are facing the problem of operating more cars, while their generating and distributing systems are already loaded to their full capacity. The reduction in power consumption with slow-speed motors would mean that more cars could be operated without increasing the generating and distributing capacity. So the questions of motor speed and gearing are exceedingly important when considering the installation of a new system or a new line. It is unfortunate that this has not been better appreciated in the past.

Combined City and Suburban Service. Here are considered those lines giving a mixed service consisting in part of city service as defined above and in part of a service averaging four or five stops per mile, with more or less well-defined limits.

In this class of service the same general principles hold as for city service. The possibility of using high speed is only slightly greater than in city service as the stops are still comparatively frequent.

For example assume that the operation of a certain line comprises six miles of city running with nine stops per mile and six miles of suburban running with five stops per mile. The minimum running time without any coast is 68.8 minutes for the slow-speed motor and 68 minutes for the high-speed motor, a difference of 0.8 minute or 1.16 per cent. On the basis of a schedule time of 81 minutes for the run one way and operation of the two motors as shown in Figs. 1 and 2, the power consumption with the high speed motor is 42.54 kw-hr. per trip and with the slow speed motor is 39.9 kw-hr. per trip, the latter saving 6.2 per cent of the energy required by the former.

In this class of service the annual car-mileage is generally higher than in city service only, on account of the longer trips, somewhat higher average speeds, and smaller difference between the average and maximum number of cars required at different times of the day and year. Assuming 40,000 miles per car yearly and power at one cent per kw-hr., the saving by using the slow-speed motor instead of the high-speed motor amounts to $46.00 annually.

Interurban Service. Practically all interurban railways enter

one or more large towns or cities over tracks laid in the streets for several miles. This condition generally requires slow-speed running whether the stops are few or frequent and therefore this part of the service is most economically maintained by the slowest speed gearing suitable for the other service. Many of these railways give both local and limited service. It is of course desirable to use the same motor and same gear ratio for both classes of service. With the same gearing, the local service, because of the more frequent stops, will work the motors more nearly up to their full capacity than will the limited service. The limited service is most often considerably less than half of the total. In order to minimize the size of equipment and get the maximum economy of power, the gear ratio should be selected on the basis of the local service, and the limited schedule adjusted to suit the equipment and gearing best adapted to the local service. If a high speed limited schedule is taken as the basis of choosing the gear ratio, one of two evils frequently results; (1) A small equipment geared for abnormally high speed and just able to maintain the limited schedule nicely is selected with the inevitable result of overheating the motors in local service, roasting out the windings, loosening connections and consuming an unwarranted amount of power; or (2) a large equipment geared to maintain the limited schedule and yet of sufficient capacity to perform the local service without overheating is chosen with the result that the power consumed in local service is excessive and equipments are heavier than need be for the major portion of the service. With the large motor geared for a high limited schedule, the heating in local service is as great as with the smaller motor properly geared for the local service.

Large high speed equipments collect their toll all along the line through extra weight, first cost, cost of maintenance, cost of power, greater feeder capacity, larger substations and larger power houses. Is it worth the price? We believe it is not. In certain cases of keen competition, it may rise to the dignity of a *necessary* evil, but too often high speed is assumed as the essential element in building and maintaining traffic when in reality the frequent service and ability to receive and deliver passengers at several central points in the terminals and towns served, assures all the profitable traffic.

In the last analysis we believe that the extra cost of excessively high speed limited service is rarely equalled by the additional revenue obtained on account of the excess in speed over what could be secured with equipments geared for moderate speed.

Table II shows that the power consumption per car-mile for local service is 2.4 kw-hr. with 75 h.p. motors and 2.7 kw-hr. with 100 h.p. motors and for limited service is 2.03 kw-hr. and 2.39 kw-hr. with the 75 h.p. and 100 h.p. motors respectively.

III. Correct Operation

We have shown that very great economies may be obtained by selecting motors of the proper armature speed and correct gearing. In addition to these, a great saving in power consumption may be secured by correct operation of the cars in service. By correct operation is meant the use of proper accelerating and braking rates so as to obtain the greatest amount of coasting consistent with the particular equipment used in any given service.

Acceleration. It is frequently found that where a road is

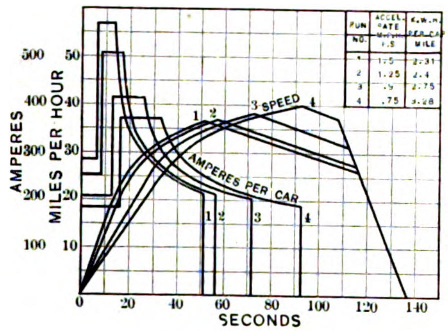


Fig. 4.

operating under a fairly easy schedule, the motormen will accelerate rather slowly and perhaps operate with the motors connected in series for a considerable part of the time. The limits to the rate of acceleration are the strains on the car and equipment and the comfort of the passengers, so that all of these features should be considered in determining the maximum rate of acceleration which is permissible in any given case. So far as comfort is concerned, rates of acceleration up to 2 min.per hr. per sec. are in use without objection on the part of the passengers.

Fig. 4 shows a run of one mile at a schedule speed of 24 mi. per hr. with various rates of acceleration. The car weight is 38 tons and the equipment comprises four motors each rating 75 h.p. at 500 volts. The breaking rate is constant at 1.25 mi. per hr. per sec. A consideration of this figure shows that by varying the

acceleration from 0.75 mi. per hr. per sec. to 1.5 mi. per hr. per sec., the power consumption may be reduced 29.6 per cent. It should be noted in this connection, however, that the maximum current requirements vary from 370 amperes per car with the lowest rate of acceleration to 570 amperes per car with the highest rate of acceleration. Hence substation and line capacity must be considered in many instances.

Coasting. The amount of coasting obtained is a fairly good measure of the difference in power consumption for a given run made under different conditions; because when the amount of coasting is great, it usually means that the acceleration is rapid and that the breaking rate is also high. The actual economy obtained by increasing the amount of coasting in any given service is not affected during the coasting period itself, but is the result of

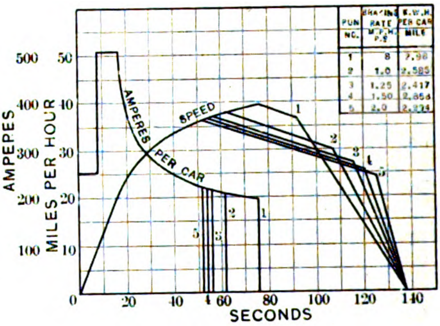


FIG. 5.

(1) more rapid acceleration with power taken from the line a decreased proportion of the time, and (2) of a higher breaking rate with decreased waste of energy in heating the brake shoes and wheels.

Braking. Other things remaining the same, an increase in the breaking rate produces a decrease in power consumption because the brakes will be applied at a lower speed and consequently there will be less of the stored energy of the car consumed during the braking period. This saving is indicated directly by the decreased time during which it is required to supply power to the car in order to maintain a given schedule.

Fig. 5 shows the same run as in Fig. 4 except that a constant accelerating rate is maintained and the braking rate is varied. By varying the braking rate from 0.8 mi. per hr. per sec. to 2.0

mi. per hr. per sec., the power consumption is reduced 23.1 per cent.

Fig. 9 is a general curve showing the rheostatic losses in an equipment, plotted against the speed at which the rheostats are all cut out of the circuit, the stored energy in a car at any speed, and the power input to the car in bringing it from rest up to any given speed. The energy to propel a car is utilized in heating the electrical equipment, overcoming rheostatic losses in starting, in heating brake shoes and wheels and in overcoming the friction and windage due to operating the car in service. The latter item is the useful work and is practically constant for a given service irrespective of the method of operation.

By using a motor so designed and geared that the rheostats will all be cut out of circuit at a low speed, the rheostatic losses will be below those obtained when the rheostats are cut out of circuit at a higher speed. With a given equipment, increasing the rate of acceleration, produces this result. Higher rates of acceleration permit the car to coast to a lower speed before the brakes are applied and therefore less energy is wasted in heating the brake shoes and wheels. High rates of braking accomplish the same result.

The curve in Fig. 9 marked "rheostatic losses" shows what may be accomplished by cutting out the rheostats more quickly. The curves marked "stored energy no rotational" gives a measure of the amount of energy wasted in braking from any given speed and shows what may be accomplished by applying the brakes at a lower car speed. This curve is used in preference to the one including the energy of rotation in armatures, gears, wheels and axles since this rotational energy will be about balanced by the train resistance while braking. The curves for field control will be considered later.

The coasting clock has been used with considerable success in decreasing the power consumption by inducing the motormen to accelerate and brake at higher rates. There are two points to guard against in its use, however; one that the rates of acceleration and braking be not forced up to such a point that both excessive mechanical and electrical strains may be imposed upon the equipments with a resultant increase in the maintenance account; the other, that when the transportation department find that a certain schedule can easily be maintained with 30 or 40 per cent of the time spent in coasting, they must not yield to the temptation to decrease the running time, and run the risk of over-heating the equipments.

IV. Field Control

The control of the speed of railway motors by changing the effective turns on the field, is as old as railway motors. Practically all of the early double reduction motors were controlled in that way. Some few single reduction motors were also controlled in that way and the old "loop" system was quite familiar fifteen years ago. It was a failure at that time chiefly because of difficulties with commutation due to poor motor design. Its advantages have remained fresh in the minds of some engineers, however, and when the locomotives for the New York, New Haven & Hartford Railway were designed in 1905, they were

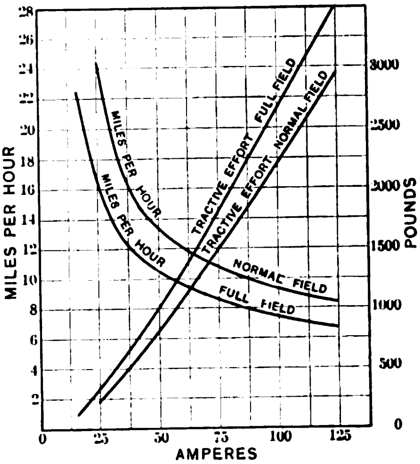


Fig. 6.—Field Control—40-h.p. Motor—5.12 Gear Ratio—33-in. Wheels—500 Volts.

arranged for speed control on direct current by shunting the field. Forty-one locomotives have been in operation with this system of control on this road for the last five years and it has proven entirely satisfactory.

When the giant Pennsylvania locomotives were designed, the requirements for large tractive effort in starting and high maximum speed were so severe that it was necessary to use field control of the motors. The application was slightly different from that of the New Haven locomotives, however; instead of shunting the field, half of it is cut out on the final notches in series and parallel. This is to avoid having a non-inductive shunt around the field which with a solid frame machine might

be productive of flashing. This is the scheme which has since been tried with great success on motors for city and interurban cars.

The question that naturally arises is, what are the advantages of this system? The answer is brief, to save power. How is this accomplished? On the same general principle which saves power by the use of slow speed motors and high gear ratios; namely, more efficient acceleration. In Fig. 9, the rheostatic losses with field control are less than for the same speed with ordinary control because field control is used in series in place of the last resistance step. Fig. 6 shows the speed and tractive effort curves of a 40-h.p. field control motor with maximum gear ratio

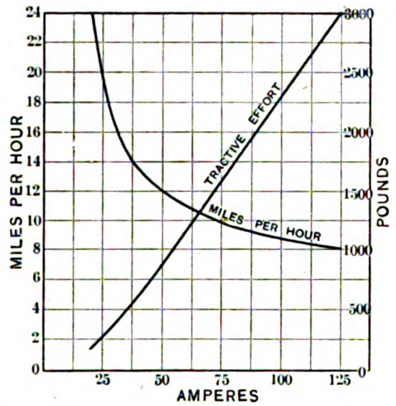


FIG. 7.—STANDARD 40-H.P. MOTOR—5.12 GEAR RATIO—33-IN. WHEELS —500 VOLTS.

and 33-in. wheels. Fig. 7 shows the characteristics of the corresponding slow speed motor without field control, and Fig. 8, the corresponding light weight motor. From these curves it is seen that the speed of the field control motor on normal field is about the same as that of the slow speed motor without field control, while the speed of the field control motor on full field is very low. The full field is used in accelerating and therefore the rheostatic losses are greatly reduced. The normal speed is used for running and enables the car to attain the same speeds as with the non-field control motor, so that the braking losses are not increased.

The following example will serve to show the saving which may be obtained by field control. Suppose that the tractive

effort per motor required to give the necessary acceleration is 1575 lb. With a non-field control motor this takes 75 amperes and with a field control motor only 68.5 amperes. The rheostatic losses are all cut out at 8.9 mi. per hr. with field control motor, but are not cut out until a speed of 9.9 mi. per hr. is reached with the non-field control motor. Reference to the general curve Fig. 9 will show that the corresponding rheostatic losses are 1.07 watt-hours per ton with the field control motor and 1.62 watt-hours per ton with the non-field control motor. In other words, the field control motor saves 0.55 watt-hours per ton every time the car starts. If the car weighs 30 tons and

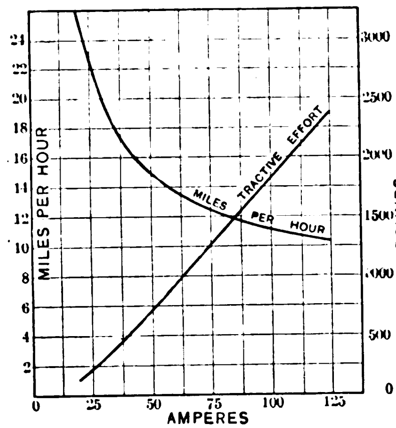


FIG. 8.—LIGHT WEIGHT 40-H.P. MOTOR—5.12 GEAR RATIO—33-IN. WHEELS—500 VOLTS.

makes 9 stops and starts per mile, the saving is 0.149 kw-hr. per car-mile.

Fig. 3 shows the same run as in Figs. 1 and 2 made with the same acceleration as used for the slow-speed motor in Fig. 2. Table I gives the results from Figs. 1, 2, and 3. The power consumed is 3.39 kw-hr. per car-mile or 9.6 per cent less than with the slow-speed motor of Fig. 2 and 19.5 per cent less than with the high-speed motor of Fig. 1. In this case, the use of a slow-speed motor instead of a high-speed motor reduces power consumption 10.9 per cent while the use of field control makes a further reduction of 9.6 per cent and the combination of slow-speed motor and field control produces a saving of 19.5 per cent.

For a combined city and suburban service, similar results are obtained. The application of field control to the example of this class previously considered under Section II, shows that the field control motor will make the trip with 35.76 kw-hr. and therefore will save 10.4 per cent of the power used by the slow-speed motor and 15.9 per cent of that required by the high-speed motor.

TABLE I

Length of run—ft.	587	1056
Time of run—sec.	43.4	61
Stops per mile	9	5
Length of stop—sec.	7	7
Schedule speed—mi. per hr.	9.2	11.8
Braking rate—mi. per hr. per sec.	1.25	1.25
Motor equipment	4–40 h.p.	4–40 h.p.
Gear ratio—33-in. wheels	5.12	5.12

Motor type	Light wt.	Standard	Field con.	Light wt.	Standard	Field con.
Motor rev. per min. at 40 h.p. at 500 volts	608	526	445	608	526	445
Amperes at full load of motor.	72	72	73	72	72	73
Car weight—equipped and loaded—tons	29	30	30	29	30	30
Accelerating current—amperes per motor	75	75	68.5	75	75	68.5
Accelerating rate—mi. per hr. per sec.	1.5	1.88	1.88	1.5	1.88	1.88
Speed at which rheostats are all out	12.4	9.9	8.9	12.4	9.9	8.9
Coasting time—sec.	7.5	7.5	10.8	19.8	13.3	20.8
Speed at time brakes are applied—mi. per hr.	16.2	15	14.5	15.3	16	14.7
Watt-hr. per ton-mile	145	125	113	99.3	96.7	85.7
R.m.s. amperes per motor	38.3	33.3	32.4	33.9	30.4	29.7
Temp. rise in service from air 25 deg. cent.	65	47	45	50	42	40
Kw-hr. per car-mile	4.21	3.75	3.39	2.88	2.90	2.57

For interurban service, field control produces more economical running over the slow-speed city sections, permits the use of a gear ratio which is economical for local service and with the same gearing gives a higher limited speed than could be obtained with the same size non-field control motor geared for the local schedule. This tends not only toward economy in local service, but also towards reducing the motor capacity required for

the operation of frequent-stop local service and high-speed limited service with the same gear ratio.

A 75-h.p. field control motor geared for local service, as heretofore described, and operating as shown in Fig. 10, will maintain a limited schedule speed of 38.4 mi. per hr. which is the same as that possible with the next size larger non-field control motor. At the same time the reduction in power consumption is 15.9 per cent for local service and 11.7 per cent for limited service. The power consumption in limited service is somewhat more than with the ordinary 75-h.p. motor on account of the faster schedule speed maintained with the field control motor. The comparative results are shown in Table II.

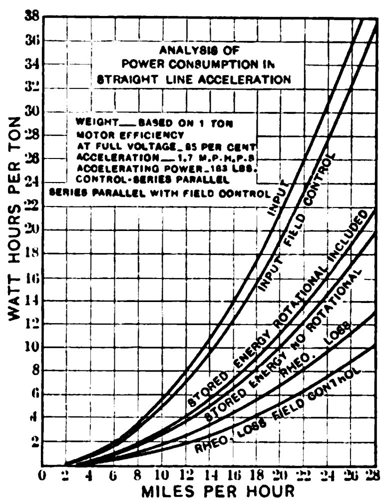


Fig. 9.

V. Results of Tests

Within the last few years, a number of tests have been made on cars operating in regular service, the results of which show that our contentions in respect to proper gearing and armature speed, correct operation and field control are correct in practise as well as in theory.

Table IV shows the results of tests made in December, 1910, under the direction of the writer, on the Frankstown Avenue line of the Pittsburgh Railways Company. The cars and equipments in this case were identical except for gear ratio.

Test A was made with a slow-speed gearing, while test B

was made with a higher-speed gearing. A comparison of the service conditions shows that they were approximately the same —the slightly higher schedule speed in test B being balanced by the somewhat fewer stops and slow-downs, shorter duration of stop and decreased average passenger load. The railway company had in service a number of cars equipped as for test B.

The car geared as for test A was operated in regular service for a considerable period of time prior to the tests and proved itself capable of maintaining the schedule equally as well as the car geared for higher speed. It will be noted that not only did the tests show that the low speed gearing effected a saving of 13.8 per cent in the power consumption, but they also showed that, whereas the equipments with the high-speed gearing were operating with dangerous temperature rise, with the low-speed

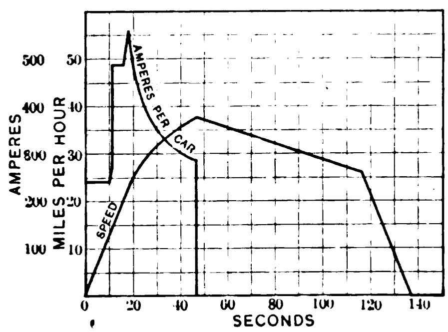


Fig. 10.

gearing the heating of the motors was just within safe limits. All equipments of these same motors installed since these tests were made, have been provided with the slow-speed gears.

In volume XXIX, page 1484 of the A. I. E. E. Transactions, Mr. H. St.Clair Putnam makes the following statement regarding the use of coasting clocks on the Manhattan Elevated Railway in New York: "The result of these calculations and tests shows that an increase in the percentage of coasting from 12 per cent to 37.5 per cent will effect a saving of 24 per cent in the power required for traction."

The report of tests, made on cars of the Chicago Railways Company, as given in the *Electric Railway Journal*, volume XXXVII, pages 1192 and 1200, shows that increasing the accel-

erating and braking rates (through the use of coasting clocks) will save 15.6 per cent of the power required for traction without special effort on the part of the motorman, and that it is possible and practicable to increase this saving to 27 per cent. This report also shows that there is a saving in brake shoes amounting to 40.8 per cent.

Both of the above reports show what can be accomplished by correct operation as induced by the application of coasting time

TABLE II.

Length of run—miles		1			6	
Time of run—seconds	150	150	150	611.8	563	563
Length of stop—seconds	12.5	12.5	12.5	60	60	60
Schedule speed—mi. per hr.	24	24	24	35.3	38.4	38.4
Accelerating rate—mi. per hr. per sec.	1.25	1.25	1.25	1.25	1.25	1.25
Braking rate—mi. per hr. per sec.	1.25	1.25	1.25	1.25	1.25	1.25
Motor equipment	4–75 h.p.	4–75 h.p.	4–90 h.p.	4–75 h.p.	4–75 h.p.	4–90 h.p.
Motor type	Standard	Field control	Standard	Standard	Field control	Standard
Amperes at full load of motor	130	130	156	130	130	156
Car weight—equipped and loaded—tons	38	38	39.5	38	38	39.5
Accelerating current—amperes per motor	127	122	177.5	127	122	177.5
Speed at which rheostats are all out—mi. per hr.	21.3	20.3	28.2	21.3	20.3	28.2
Coasting time—seconds	60	70	77.5	67.8	86.2	86.7
Speed at which brakes are applied	27.1	26	25.7	30	30	30
Kw-hr. per car-mile	2.4	2.27	2.70	2.025	2.11	2.39
Watt-hr. per ton-mile	63.2	59.7	68.4	53.4	55.5	60.5
Temp. rise in service from air 25 deg. cent.	58°C.	60°C.	70°C.	50°C.	58°C.	60°C.

recorders. It should be noted in connection with the Chicago Railways Company service that the equipments now maintain the schedule so easily that the gearing is being changed from 4.06 to 4.73 in order to reduce the peak demands. Incidentally it may be noted that one of the dangers previously mentioned in connection with the application of coasting clocks is beginning to show itself here, as the Chicago report states that the running time for the cars on the line tested has been reduced three minutes. In any such case, care should be exercised to determine

TABLE III

TESTS IN NEW YORK SHOWING EFFECT OF GEAR RATIO AND FIELD CONTROL ON POWER CONSUMPTION

Test number	Weight of loaded car-tons	Motor	Rev. per min. 40 h.p.	Gear ratio	Stops per mile	Slow-downs per mile	Average length of stop sec.	Schedule speed miles per hr.	Average volts	Watt-hr. per ton-mile	Remarks
1	20.214	Standard 60 h.p.	560	4.6	6.975	2.86	8.503	7.126	557	152.26	
2	19.729	Standard 40 h.p.	550	5.12	6.778	3.08	7.765	7.261	556	141.63	Normal field on field control motor.
3	20.153	Field control 40h.p.	445	5.12	8.333	3.11	7.240	7.142	551	133.85	In congested district ran in series only.
4	19.714	Field control 40h.p.	445	5.12	6.881	3.56	7.335	7.409	555	124.41	

2—Saves 7 per cent of power used by 1—Reason, 12 per cent less car speed at 40 h.p.
3— " 5.5 per cent " " " 2— " field control.
4— " 7 per cent " " " 3— " fewer stops.

4—Saves 12 per cent of power used by 2—Reason, field control.

what effect upon the heating of the motors such a reduction in running time may produce before faster schedules are adopted generally. More or less protection against too rapid acceleration may be secured by careful circuit breaker adjustments or automatic acceleration, or by a graduated scale with respect to the bonus offered motormen in connection with their coasting time records.

Table III shows the result of a series of tests made on the cars of the Metropolitan Street Railway Co. of New York under the direction of Mr. H. H. Adams. It will be seen from this table by comparing tests I and II that the use of a slower speed

TABLE IV.

TESTS ON FRANKSTOWN AVE. LINE OF PITTSBURGH RAILWAYS COMPANY

Showing effect of gear ratio on power consumption and motor heating.

Items	A	B
Weight of motor car without load—lb.	49,000	49,000
Weight of trailer car without load—lb.	23,000	23,000
Motors	4-50 h.p.	4-50 h.p.
Gear ratio—33-in. wheels	4.6	3.67
Schedule speed—mi. per hr.	9.15	9.50
Stops per mile	8.7	8.63
Slow-downs per mile	1.94	1.37
Average duration of stop—sec.	6.8	6.2
Average passenger load	37	30
Average voltage	483	480
Watt-hours per ton-mile	137	159
Average temperature rise on armatures corrected to 25 deg. cent. air temperature	68.8	87.8

A saves 13.8 per cent of the power used by *B;* reason—correct gearing. Day's service consisted in each case of two round trips with trailer, then three round trips without trailer, followed by two round trips with trailer.

armature and greater gear reduction effected a power saving of 7 per cent. In test III, throughout the congested district the equipments were operated in series only and then operated in series and parallel on the remainder of the runs. In spite of the fact that this test shows nearly 23 per cent more stops than test II, the power consumption was decreased 5.5 per cent due to the use of field control.

In test IV the number of stops and other service conditions are practically the same as in test I and II but the motors were operated making full use of the field control in series and parallel over the entire line. This test showed 7 per cent less power consumption than test III with its greater number of stops and

12 per cent saving in power in comparison with test II, where the service conditions were practically the same. Substantially all of this saving was due to the use of the field control motor in test IV as against the non-field control motor in test II. In this connection, it should be noted that while the 60-h.p. motors of test I showed an average temperature rise of about 48 deg. cent. corrected to air at 25 deg. cent., the 40-h.p. motors in test IV showed only 58 deg. cent. temperature rise, which is still perfectly safe operating condition.

Tests recently made on various lines of the Pacific Electric Railway showed an average power consumption of 97.3 watt-hour per ton-mile with quadruple 75-h.p., 650-rev. per min. motors geared 2.18:1. Other 75 h.p., 640-rev. per min. motors geared 3.24:1 showed an average power consumption of 87 watt-hour per ton-mile. The latter motor with field control showed an average power consumption of 81 watt-hour per ton-mile. These figures indicate that proper gearing would effect a power saving of 10.6 per cent in this service, while the application of field control would produce a further saving of about 6.9 per cent and the total saving which could be obtained by the use of correct gearing in combination with field control will be about 16.8 per cent. It is interesting to note further in this connection that the average temperature rise of the motors, corrected to air at 25 deg. cent., in the most severe service was 80.5 deg. cent. for the motors geared for high speed and 61.2 deg. cent. for the field control motors. Temperatures on the non-field control motor geared for low speed in this service are not available at the present time.

Summing up the results of calculations and tests as previously described in detail, it is found that proper gearing and armature speed, correct operation and field control are essential to the most economical operation of railway service and the indications are that from 10 per cent to 30 per cent of the power now consumed in specific cases may be saved by a careful study of the operating conditions and the intelligent application of these principles.

Discussion on "Some Notes on Isolated Plants" (Moses), New York, January 12, 1912. (See Proceedings for January, 1912).

(*Subject to final revision for the Transactions.*)

R. P. Bolton: I will draw attention to some of the features which the author has introduced as being of an informative nature and upon which you are invited to base future action and practise, and of which the diagrams presented purport to be indexes or guides. A casual observation shows that they omit consideration of a very important element of variation in output and demand on the part of these appliances. They seem to be based upon the sole consideration as to whether electricity be purchased or be manufactured, in the case of those on the left side of the page, and on the further consideration, in the case of the right-hand diagrams, of whether a certain amount of steam, more or less, would be required and provided by the apparent electrical output. The isolated plant, however, operates under summer conditions and under winter conditions, the demand for steam heat being climatic, intermittent, and irregular, while the demand for electric lighting is also intermittent and irregular—therefore how can conditions as laid down in the diagrams be used to determine the relative proportions or even the kind of apparatus to be installed in different plants? It is an open question whether or not it is desirable for steam-driven fans to be installed for indirect heating systems in connection with purchased electricity. The conditions might be such that it would be highly undesirable from an economic standpoint to make such a combination, and more particularly so if the process involved the employment of extra labor, which after all is the main element to be considered in connection with all the items in these diagrams, and one which does not appear in them at all.

It is a remarkable and interesting fact, which appears very frequently in connection with isolated plant design and operation, that low efficiency and wasteful lighting is regarded as an element which does not disturb the overall efficiency of the isolated plant.

I cannot agree that the building on Fifth Avenue, mentioned in the paper, is typical of office building conditions, for the diagram (curve 12) shows that the load curves of its plant are not typical of office building duties. One curve illustrated shows the apparent output used in the building, and another that of the building combined with the output used in another building, an interesting combination, to be sure, but one which does not carry with it conviction. Nor does the information given in connection with the building allow an analysis which would offer necessary directions to a designer in planning a new plant upon similar bases.

In regard to office building curves, there is a great deal omitted from the paper which would have been of value. These buildings are operated, in this as well as in other cities, on low factors of load and also on low factors of time, operating the

plant on a ten or twelve-hour service, on the working days of the year, which, including the Saturday half-day service, are equivalent to 278 days of 10 or 12 hrs. The rest of the year is made up of lost or idle time on Saturdays, Sundays, and public holidays, and the night periods of all, resulting in a combination of conditions very unfavorable to the operation of steam and other generating apparatus. In the Trinity Building, No. 111 Broadway, the maximum peak load in October, which may be taken as an average of the year's condition, occurs at 4.30 o'clock, and has a tendency to shift as the winter proceeds, occurring at an earlier hour in the afternoon, and then gradually shifting to a later hour. The building is equipped with the highest class of machinery to be secured at the time of its installation, and has units of a sufficient number to divide the load in a reasonable manner, and with a reasonable expectation of efficiency, yet on an October day, when the load reached about 3,000 amperes, at 4.30 p.m., the all-day load factors were as follows: of the sets under steam, 37.6 per cent; of the total installation, 28.22 per cent.

Inasmuch as all classes of small steam engines fall off very rapidly in efficiency, and increase their steam consumption very rapidly, as the load factor decreases, the conditions must be very unfavorable to economical operation. When conditions occur such as on holidays, summer afternoons and during night service, poor economy results. A typical Sunday load on December 3 was as follows: The all-day load factor 12.21 per cent of the sets under steam, and only 3 per cent of the entire installation. Such conditions are not, therefore, favorable to the operation of steam engines.

I draw your attention to the fact that some of the diagrams of load curves presented omit a very essential element, the variations introduced by elevator service, which constitute a certain proportion of swinging load above the load here recorded. For the purpose of comparing and deciding upon the proportions of another plant, under similar circumstances, what information can be gained from diagrams consisting of observations of a steady load, irrespective of the surges of elevator service, inasmuch as elevator service constitutes an element of prime importance in all plants of any magnitude to-day?

The author introduces daily log sheets of records in certain classes of buildings. It is evident upon a glance at these sheets, that many of the elements which were supposed to be recorded are omitted, and that they do not afford any definite information, either by summarization or by note, such as may enable anyone to derive any determinate conclusions therefrom.

John C. Parker: I am very glad to see that Mr. Moses has laid stress upon the fact that the isolated plant should be treated as a whole. I think we too often in our engineering practise are likely to concentrate attention on details, insisting on perfection here, perfection there, or perfection in the other place, without

considering whether the aggregate of perfections constitutes perfection in the whole. The fact that the isolated plant is to be handled as an entity rather than as a group of disjunct units, is one on which stress can very advantageously be laid. This is so much the case that it becomes very important that the isolated plant be considered not only as an electrical energy generating device, but as a heating device as well. This fact makes it rather regrettable that Mr. Moses has given a good many of the details of cost of fuel and labor for heating in buildings without private electric plants, in a general form rather than specifically. The fuel consumption of a building of a certain size, of certain superficial area, with a certain number of floors and used for certain business, is not in itself particularly valuable. The conditions in different manufacturing plants vary so much that even had the fuel consumption for heating purposes been given, that would not in itself have been sufficient evidence, because climatic conditions in various localities differ, the percentage of glass in the exposed walls of buildings naturally differs with the style of architecture, and the character of the construction of the side walls makes a tremendous amount of real difference in the fuel consumption for heating.

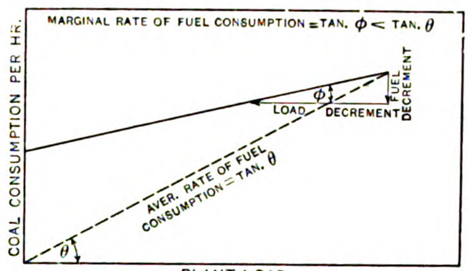
It is quite unfortunate that Mr. Moses has not reduced the extensive data in his paper to formulas, so that the members could have the benefit of his experience in deriving the constants of various buildings for heating purposes. I think it would be a considerable contribution to the PROCEEDINGS if, in his final summing up of the discussion, Mr. Moses could reduce some of the data secured in his extensive practise to formulas. Those of us who have to calculate the heating requirements of buildings find a tremendous dearth of data giving the building constants.

In regard to the table of costs of plants per kilowatt capacity, I notice that for a medium speed direct-connected plant we might expect the investment cost to run between $90 and $125 per kilowatt. My own experience in investigating something like 500 industrial plant propostions has indicated that these figures are perhaps a little low for plants of the best type and of medium size—say up to 500 kw. The discrepancy between my own observation and that of Mr. Moses may be due, perhaps, to the fact that these plants have not required a building, and I have failed to find the stack cost represented in the tables in Mr. Moses' paper. Where a plant is put in a basement or sub-basement, no separate building has to be put up for it, but one would still expect to find some part of the building cost chargeable to the plant.

I ask if Mr. Moses intended the figures to cover the overhead costs, which I suppose might add anywhere from $4 to $10 a kilowatt to the cost of the plant.

I am very much interested in one point brought out in Mr. Moses' paper, and that is that the highest efficiency apparatus is not always to be sought—that there are times when, as Mr.

Bolton expressed it, the less economical the apparatus, the more economical it really is in operation. I think the principle can be pushed a little further than Mr. Moses has done in his paper. It is not altogether a matter of running a plant to supply exhaust steam, but we do find differentiating conditions, between purchased power and isolated plant power, if you will, due to still another cause. We find that the use of highly efficient power-utilizing apparatus and lamps may be desirable in one isolated plant and not in another. The reason is this: unless the isolated plant has approached the limit of its capacity, the installation of highly efficient lighting units, we will say, will make reduction in only two places; namely, the fuel and the water cost. I will roughly indicate this by a diagram, which is not intended to be quantitative. The aggregate fuel may be plotted as ordinates, and the kilowatts load as abscissas. The curve then might be expected to be something in the nature of a straight line intersecting the ordinate axis at some distance above the origin. Now, in cutting the load off from the top, we find that while the average fuel consumption of the plant might be something like



five or six pounds (2.3-2.7 kg.) per kilowatt-hour, the reduction in fuel consumption by drawing off load would not be in anything like the ratio of five or six pounds to the kilowatt-hour, but in a much smaller ratio, since the reduction in fuel consumption is at the point where the consumption is the most economical. Fuel consumed on the light load part of the plant has borne all the burden and heat of the day, and it, therefore, follows that the eleventh-hour consumption follows the biblical analogue and gets through very easily. Now, from this it follows that, except in the cost of a plant which is pushed to the limit of its capacity, one cannot afford to spend a great deal on highly efficient motor drive, and on efficient lighting units, as could be done where power is purchased from the outside, since in the former case no saving is made in plant investment, labor cost, et cetera, and at the best, an incommensurably small saving of fuel and water; while in the latter case a reduction in load affects equally the kilowatt-hour consumption and the kilowatt demand.

Practically all sales rate schemes are based on three charges:

one a customer charge, which is not affected by anything you may do in the way of efficient operation; another charge based on the kilowatt demand, which is, of course, affected by efficient operation; and another charge based on the kilowatt-hours of energy, a condition which would be similar in a degree to the condition in the laying out of a contemplated isolated plant. There, if your lighting load, or the economies you would make by highly efficient power distributing apparatus, were relatively small, you might be able to get along with a smaller plant.

However, even in this case, the general principle still obtains, since plant cost will follow a curve approximately of the same sort as shown above, and therefore efficient distributing and consuming devices will save only a part of the fuel and water, none of the labor, and only the cheapest part of the apparatus investment.

The point I wish to make in all this is that what the economists know as the " law of diminishing returns," otherwise expressed by the speaker in his paper on fixed costs, presented before the Institute March 10, 1911, as the " marginal principle." must be applied to all of our studies, without assuming that because efficiency is to be sought at a price in one case, it may of necessity be the desideratum in all cases.

To show just how far the principle brought out by Mr. Moses does apply, I want to take the very simple case of the carbon and the metallic filament lamp. I have assumed the ordinary 16-c.p. carbon lamp, consuming 3.5 watts per candle, and compared it with a 20-watt tungsten lamp, delivering the same amount of light, 16 c.p. There is a difference of 36 watts in the consumption of the two lamps. Assuming a life of 1,000 hours for the lamp, and assuming that the marginal coal consumption is 2 lb. (0.9 kg.) (by the marginal coal consumption, I mean the coal consumption due to the last portion of the load added to your plant) and figuring the cost of the fuel, and water evaporated by the fuel, at $3 per ton, we find that the use of the tungsten instead of the carbon lamp will save 10.8 cents during the life of the 20-watt tungsten lamp. Now, on the other hand, let us assume we are purchasing power. Taking figures merely typical, not pertaining to any particular locality, let us assume the power is purchased on a demand charge, we will say of $2 per kilowatt per month, and in addition to this, at 1.5 cents per kilowatt-hour of energy consumption. The saving by the use of the tungsten lamp over the carbon lamp would be 36 watts, times the thousand hours of lamp life, divided by 1,000 to reduce to kilowatt-hours, times the 1½ cent charge per kilowatt-hour, or 54 cents, to which is to be added a further reduction of 0.046 kilowatts at $2 for 1,000 hours, divided by 200 hours, the assumed monthly hours of burning, which equals 46 cents. This makes a total of $1 saving, as against something less than 11 cents in the case of the isolated plant, where you are not pushing the limit of plant load.

This illustration is a simple one that I thought would be interesting as laying further stress on the fact brought out by Mr. Moses that the higher efficiency apparatus is not always the best; that the isolated plant is not able to avail itself of the efficient devices that can be used with purchased power, where the consumer is not dependent upon a fixed investment.

Please note that the principle here laid down is not of necessity always applicable against the isolated plant, but that in general it does apply when the plant is not being pushed to the limit of its capacity; and that even in the design of a brand new plant, one cannot always take advantage of such a principle, unless the demand load reduction is big enough to make a material difference in the size of plant installation, and then only to a partial degree.

It must not be thought, as might superficially be done, that the greater saving by the use of efficiency apparatus in the case of purchased power, is due to the inherently higher cost thereof, but rather that this greater saving can be effected through a flexible rental of the station equipment.

Arthur Williams: I have some reluctance in attempting to present to you the other side of the question that has been so carefully and ably presented to you to-night. At the outset perhaps it is only fair to say that I personally stand on the other side of the question, partly because of my professional relationship to the industry, and partly because I believe that that is the side of economy and efficiency, and of the greatest benefit to those who need modern service in modern buildings.

The author states that the installation of a private plant in one building last year, or the year before, effected an economy of $12,000, or approaching $12,000. The admitted figures are that a gross saving of about $11,500 was effected, of which the consulting engineer received one-third, between $3,000 and $4,000, thus reducing the saving to the owners by that amount, or, let us say, to $7,000. This $7,000 is made up of a number of economies that the consumer himself might have availed himself of. The consumption of current was increased to such an extent that there would be an estimated saving, at the normal rate prevalent in New York, of $3,000 a year. I understand that it cost about $30,000 to put the plant in, and allowing as little as 15 per cent a year to cover interest, depreciation and repairs, you will see the difference is immediately and automatically wiped out.

It is not necessary for me to point out that depreciation need not be the question of the physical life of the plant. It arises from the supersession element, either from improved machinery, or from similar service being obtainable from another source. I do not think the premise can be fairly questioned, that instead of 15 per cent, the depreciation of the first year was 100 per cent, and to whatever actual cost is shown by the books of this consumer should be added the cost of installing the plant, in the neighborhood of $30,000.

The author makes reference to the fire protection to be obtained through the presence in the building of a large engineering force. I regret exceedingly the immediate occurrence of an illustration which shows how utterly incorrect is any such conclusion. I have in mind, and perhaps you all have, the fire which occurred this week, that of the Equitable Building, where the engineers, because they were in the building, spent fourteen minutes according to some witnesses, according to others, twenty minutes, trying to extinguish the fire themselves. It is a well known fact that the first three or four minutes are of supreme importance in the extinguishing of a fire. And I submit to you that if that building had had no engineering staff, simply a janitor on duty at night, or a watchman, the first thing such a man would have done would have been to send in an alarm to bring out the fire department. If that had been done—I do not speak with personal knowledge—but if that had been done, our competent fire department would have extinguished the blaze before the lapse of twenty minutes, which expired between the time the fire was discovered and when the alarm was sent in I am of the opinion that the building most simply equipped, with least dependence on its own equipment from the standpoint of safety alone, is the best kind of investment, leaving out all other considerations.

In conclusion, I would like to draw your attention to two facts. Mr. Parker, I think, will permit me to say that he need not be surprised that the cost of the stacks is omitted, because it is the usual practise, and I have yet to find a single instance where excavation in solid rock many feet down into the ground, to be replaced with very expensive steel structure, has ever yet entered into the cost of the power plant in the building in the figures of the engineers or architects, nor has it been included in the final cost of the expense of the power plant. When Mr. Parker understands that is a common practise in New York, I do not think that he will be surprised that the cost of the stack has been omitted. In a very recent case we found on an expensive Broadway corner that there was absolutely no difference in the net income upon $800,000 spent in the erection of a 12-story building, taking street service, with all the economies that means, and an 18-story building in which the income from the additional building equipment was required to meet the enhanced expenses of putting a complicated power plant into the building. In the last analysis the percentage of the return on the value of the property was better in the erection of a 12-story building with street supply than an 18-story building with a private plant.

George W. Martin: Mr. Moses' paper presents data showing the cost per kilowatt-hour of generating electric current in a private plant.

During the last few months two cases have come to the speaker's knowledge, in which the method of figuring operative

costs is open to criticism. In conversation with the superintendent of one of the well known buildings on Broadway, the question of the cost per kilowatt-hour came up. As the plant contained hydraulic machinery for elevator operation it was necessary to segregate the elevator operating costs in order to obtain the cost per kilowatt-hour of electric generation. This was done by running the electric plant for one Sunday, carrying the same load as on week days. In this way, as the superintendent naively stated, the cost per kilowatt-hour was found to be 2½ cents, not counting repairs. The cost per kilowatt-hour including repairs is left to the imagination.

The item of depreciation is another that is often neglected. Some of the most difficult facts to impress upon the mind of any plant owners, and indeed some engineers, are that the plant is steadily growing older, that repairs are necessary each year, and that depreciation is as real a charge as the coal bill. The neglect of the item of depreciation alone has in one case, to the speaker's knowledge, well nigh resulted in the total shut-down of one of our largest office buildings.

For years this plant was operated apparently with the idea that the machinery would last forever, and as long as a pipe did not actually burst or a boiler explode, little attention seems to have been paid to the fact that the apparatus was steadily growing older. Of course, the small amount spent for repairs cut down the cost per kilowatt-hour. But not so very long ago the plant absolutely refused to work under this system of management, and it was only by the most strenuous efforts that operation was maintained.

The plant is now being entirely overhauled, and in three months the items of repairs for running have been about as follows:

New steam piping	$3,600.00
Repairs to boilers	2,500.00
Repairs to heating system	2,500.00
Miscellaneous repairs	1,000.00
Additional labor necessary to keep plant in operation two men for six months at $18 each per week	864.00
	$10,464.00

The foregoing items represent actual experience, and demonstrate the absurdity of trying to keep down plant costs by neglecting the items of repairs and depreciation.

Charles K. Nichols: The author of the paper states that "if electricity is made on the premises the exhaust steam available points to an exhaust steam operated absorption refrigerating plant;" on the following page he avers that the "refrigerating design will affect the power plant piping design because of the use in the retort or generator of steam at a higher pressure than that carried on the main parts of the plant." In other words,

it is the exhaust from the pumps of the absorption refrigerating plant, or other auxiliaries, that is used in the generator of the absorption machine and not the exhaust from the electrical generating units, as one is given to believe from the paragraph first quoted.

While it is unquestionably true that exhaust steam may be used in the generator of an absorption machine, provided a sufficiently high back-pressure is carried to meet the conditions imposed by the temperature of the water that is available for cooling—which is usually high during the summer months when the refrigerating load is at its maximum—it is most assuredly an extremely uneconomical method of attempting to utilize the exhaust from the generating units of the average isolated plant, and if the writer of the paper can point out any single instance where a private electrical generating plant in this city is utilizing the exhaust from the engines of the generating units in the generator of a refrigerating or ice-making plant of the absorption type during any portion of the year, I will be very glad of the opportunity to become acquainted with such an example of the "interdependence and interaction," upon which the author places such stress in connection with isolated power plant design.

The author states, referring to the subject of isolated plant design, that "compactness and simplicity are of the greatest importance" and then, as an evident afterthought, he remarks, "one might add reliability." The sentence last quoted is literally true if applied to the operation of the average isolated plant, and the added reliability is usually obtained in the form of an adequate break-down connection with the central station. The owner of an isolated plant, as well as those persons who are dependent upon one for their supply of light and power, would be inclined to look upon reliability of operation as being of considerably greater importance than either compactness or simplicity of design.

The figures given on the "cost of fuel and labor for heating in typical buildings with private electrical plants," are practically valueless in so far as they afford a means of estimating these items of cost for other buildings. In spite of the author's assurance that "the figures presented should allow an intelligent engineer or owner to estimate closely the probable cost of supplying steam to a building of one of the types given," they actually permit of nothing of the sort, inasmuch as the heating requirements of different buildings of the same general type of construction vary in accordance with the amount of wall and window exposures, and not in accordance with the ground areas covered and the number of stories. It is not at all unusual to find two buildings of practically the same size and the same general character where the heating requirements of one of the buildings are practically double what they are in the other, due entirely to a difference in the exposures. When such buildings are compared on a proper basis, however, these apparent discrepancies entirely disappear.

Even if the heating requirements of these buildings could be sufficiently determined from the data presented to serve as a basis for comparison with other buildings, the actual coal requirements, except for buildings 1 and 2, could not be estimated from the figures of coal cost as given, on account of the omission of the price of coal per ton.

While the figures are represented, from the heading under which they appear, as being fuel and labor costs for heating, they actually cover, in at least fifty per cent of the cases cited, by the author's own admission, the cost of producing steam for other purposes than heating the building. It will be observed that several of the buildings have steam-driven refrigerating plants, while a number of them have hydraulic elevators, operated by steam-driven pumps. It is manifestly useless to present fuel and labor costs, even if they are correct, for installations of this character, if the purpose is to present heating cost figures that may be used for comparative purposes.

The figures presented of kilowatt-hour consumption in various buildings are of little value in so far as they attempt to furnish a means of estimating the probable consumption of electrical energy in a proposed building of known size and type. The author fails to mention, in connection with fourteen out of twenty-two buildings, whether the elevators are of the electric or hydraulic type, a knowledge of which would be quite essential in order to estimate the consumption of electrical energy. In practically none of these cases is any information given as to the character of the lighting or as to the type of electric lamp that is employed. Moreover, the author fails to mention whether a private electrical generating plant is operated in the building or whether electrical energy is purchased from the central station. When a building secures a supply of electrical energy from an isolated plant, the consumption is invariably greater than it is in the case of a similar building which secures its supply of electrical energy from the central station. Where a private generating plant is installed, there is little or no incentive to practise economy in the use of electrical energy, as a result of which a reasonably low unit cost of generation may actually mean a relatively high total cost of furnishing the amount of electrical energy that is actually required.

The method described by the author of obtaining the cost of generating electrical energy in an isolated plant might be a proper one where the conditions permit of an actual determination of the so-called basic cost, but the method becomes a farce when it is necessary to estimate this basic cost.

The author states that these " basic costs " are " either actual or estimated, depending upon whether street service had been used prior to the installation of the plant or not." As the number of cases where central station service has been superseded by an isolated plant is small, it follows that the " basic cost " figures of the author are nearly all " estimated."

John W. Lieb, Jr.: If an examination is made of the schemes of operation of the plant, or diagrams of auxiliary operating practise, which the author has presented, it will be quite apparent that there has been an endeavor by the use of non-electric apparatus in one case and electrically driven auxiliaries in the other, to change what would be the logical selection of auxiliaries so that it would have a tendency in one case to elevate abnormally the production of electrical energy for the sake of getting a larger output over which to distribute unit charges and fixed costs, and to depress them uneconomically in the other case.

S. N. Clarkson (by letter): Mr. Moses has presented a most interesting and instructive paper on a subject which has become an issue in most of our large cities. The statistics quoted would indicate that conditions in New York are quite different from those existing in some other cities—St. Louis for instance.

Private plants in St. Louis get the benefit of soft 10,000 B.t.u. coal at $1.40 per ton on the cars, but they have to compete with central station rates, which are lower than in New York. Under these conditions the private plant is making but little headway and those which are already in are gradually being replaced by outside service. To make my statement more specific, I will quote the figures which are now available for the year 1911, on plants of 50 h.p. capacity and over. During that period 24 isolated plants aggregating 5,285 engine h.p. were converted to central station service and six plants aggregating 585 engine h.p. were put in. Out of the 585 h.p. installed, 265 h.p. went into one laundry.

Directors of commercial enterprises are beginning to realize that they are justified in giving the power companies an apparent bonus over and above their own plant costs because the simplicity, continuity of service and freedom from the effects of miners' and engineers' strikes are worth money to them, and then again there are many items of plant expense, especially in a factory, which cannot be separated from the general expense accounts.

The most representative apartment houses, hotels, office buildings, department stores, metal working factories, electrotypers, chemical works, bakeries, paint manufacturers, stone and marble works, clothing, coffee and spice houses, some branches of wood working, printers and many other industries are buying light, power and in some cases heat from the St. Louis public utility companies. It will be noted that in this list are some lines of business which are considered by many engineers to be the exclusive domain of the isolated plant.

It is true, as stated in the paper, that most stationary engineers believe central stations to be their natural enemy, although if they looked at the matter in a broad light all their fears would vanish. Cheap power promotes manufacturing in any locality and no men are better able to apply themselves in factories than

the trained stationary engineers. All negotiations, however, concerning a plant, are naturally conducted with the owners or managers, and as a class they will always be found ready and willing to furnish whatever data are necessary to arrive at a true comparison of the costs of operation. As intimated by Mr. Moses, the public utility companies do not accept unprofitable business, it being generally conceded that the day of the commercial philanthropist is yet to come.

The design of an economical power plant for a factory is difficult for the reason that a single unit is in almost every case insisted upon by the owner and then it must be of sufficient capacity to take care of a large growth in business, which is always hoped for, but sometimes does not materialize until the plant is worn out. In addition to the burden of inefficient operation the plant has to carry high fixed charges in proportion to the actual power demands of the factory. When such a plant is shut down and connection made to the power company's lines, and this is no uncommon occurrence, the fixed charges still go on and are an unnecessary handicap as compared with a competitor's factory in which central station service was installed originally.

There is a growing tendency among consulting engineers to advise their clients to install outside service at the outset, while at the same time making provision for the installation of a private plant at the end of a year or more of operation in the event of central station service not being what was expected. It is fully realized that in actual practise most isolated plants become less efficient and more costly to operate as years go by while the service of our public utilities is gradually becoming cheaper. The reasons for the increased costs of private plant operation, as time goes on, are not far to seek. First, the plant is given but secondary consideration at the hands of the management and is even looked upon as a necessary evil in some cases, and secondly, it is, in many cases, eventually left to the tender mercies of cheap, inexperienced help, even if a start has been made with a good man in charge. After a year or more of operation with outside service a business man will rarely install a plant; it being the consensus of opinion that the investment would earn larger dividends if put into the business. Furthermore, with central station service, the manager is free to devote his entire time and attention to promoting the business and can rest assured that his power requirements are being taken care of by experts in production and supply of that commodity. Even if conditions should develop during the period of central station operation that make it desirable to install a plant later, the data collected during that period would permit of a much more economically designed plant than would have been possible if it had been installed in the first instance, and the owner would reap the benefit as long as the plant was left in.

Internal combustion engines, which are recommended by

Mr. Moses for industrial plants having no steam requirements, have not given the expected satisfaction in any installation with which I am familiar in this country. The cost of fuel is assuredly low, but it is not sufficient to offset the low maintenance, simplicity and reliability inherent in central station service. Where attempts have been made to approach the conditions guaranteed by the public utility companies, the comparision is no longer favorable to this type of engine.

The requirements of an office building or hotel can be so closely estimated and vary so little from year to year then economical isolated plant can be more readily designed in such instances than is the case in manufacturing establishments. In spite of this, however, some of the principal office buildings, hotels and department stores in St. Louis use central station service. One of the hotels, which has had central station service from the outset, has a connected load of 400 kw., and the power plant of one of the department stores, which later changed to central station service, consisted of one 250 kw. and three 200 kw. units. I should like to know how the cost of operating the building mentioned under the heading "Effect of Interdependence on General Design," would have been affected by the use of an electrically driven refrigerating and ice making plant and a low pressure boiler. There is no question but that the cooking can be done successfully with low pressure steam 15 lb. or less, although this has been doubted in some quarters. From what I can gather of the conditions outlined, the building in question could be more economically operated in St. Louis by the central station than would be possible by running an isolated plant.

A fact that is often lost sight of is that practically every city taxes the gross revenue of the public utility companies and as a result is enabled to keep the taxes much lower than would otherwise be possible. Other things being equal, every public-spirited citizen should award business to the central station for this reason, if for no other.

Clarence P. Fowler (by letter): The general superiority of electrical energy for industrial lighting and power service over all other forms of illumination and mechanical transmission has been so thoroughly discussed as not to need further comment here. Having once settled upon the use of electrical energy for an industrial establishment, the first question for consideration is: Shall such electrical energy be of the "home-made" variety or shall it be furnished from the lines of a central station? In other words, is the existence of an isolated power plant for industrial uses justifiable, under average conditions, where efficient central station service is available? I am inclined to think that a careful consideration of all factors in most instances would point to a negative answer to this question. There exist several clear cut advantages of central station service, which, it would seem, in the majority of cases entirely preclude the commercial

advisability of the establishment of a private industrial power plant.

So far as I am aware, previous discussion concerning this matter has related chiefly to the cost of manufacturing a kilowatt-hour with an isolated plant, as compared with the actual price per kilowatt-hour as charged by the central station. While in many instances even so incomplete and inequitable a comparison between isolated plant and central station service may favor the use of the latter, it would seem that in order to make a fair comparison, additional advantages of central station service, which are frequently lost sight of, should have consideration. While some of these advantages of central station service to the power user are not always apparent and cannot always be exactly evaluated in dollars and cents, they are, however, none the less real.

Some of the advantages of central station service which may have considerable monetary value and which may, therefore, be properly regarded as effective in reducing the actual charge made for such service, may be briefly summarized as follows:

The modern progressive central station sells more to its customers than raw material, mere kilowatt-hours. In the purchase price of energy is included the finished product, efficient illumination and power service. In other words, the service of the up-to-date central station with its corps of trained specialists does not stop at the consumer's meter, but extends beyond to the customer's side. The central station of to-day solves the customer's illumination problems in the most efficient way and furnishes advice, gratis, as to the most advantageous methods of grouping his shop equipment and motor applications. The intelligent solution of these and other industrial problems is now well recognized as an important factor in accomplishment of the maximum output of labor and equipment at a minimum of operating expense. As the specialized knowledge necessary to render such advice is not possessed by the average industrial plant manager or superintendent, it is evident that if he would arrange his plant for the greatest operating efficiency it would cost him a certain amount for the engineering supervision, advice, etc., necessary to bring about such an arrangement, under isolated plant conditions.

Industrial corporations are primarily interested in the manufacture and sale of some particular product of a certain quality, at a minimum of cost, and with such corporations the question of power is merely incidental and more or less of a side issue and it is only natural to expect that the most satisfactory solution of power and lighting problems can best be left to the management of the central station, which makes a specialty of the manufacture, application and sale of electrical energy, in the same way that industrial corporations are specialists in the manufacture, uses and sale of their respective products. By the adoption of central station service, therefore, all the advantages of speciali-

zation are preserved on both sides. The lack of this specialized knowledge, necessary for the most efficient operation of isolated plants, is strikingly brought to the front by Mr. Moses in his reference to the unsatisfactory operating conditions he has found prevalent in such plants. Taking only one of the different items which he mentions in this connection, namely, the wide range of practise which he finds in a matter so important as the purchase of coal, it is but typical of the usual leaks and lack of efficient management and system in the operation of isolated power plants. To properly systematize and continually supervise the operating methods of isolated plants may cost an amount which would be considerably more than the value of the economies secured thereby, in the case of small isolated plants, and may also amount to no inconsiderable sum in the case of larger plants. These added costs, should, of course, be charged against the cost of power production on the premises.

In passing, it should be noted that the use of central station service also permits the executive heads of industrial corporations to be relieved of the effort and annoyance of supervising the operation of a private power plant. The time and attention that managers of industrial plants would find it necessary to devote to the production of "home-made" energy could, when purchasing central station service, be given over, with better results, to concentrating their energies on increased sales, cheaper production or increased output.

Another point which may frequently favor the use of purchased energy, particularly in the establishing of new industrial enterprises, a point which I believe central station sales policies have not brought sufficiently to the fore, relates to the advantages to be secured to owners of an industrial undertaking by the investment of an amount that otherwise could be required for the construction and equipment of an isolated power plant in manufacturing plant proper, thereby increasing the output by obtaining a maximum of productive equipment for a given expenditure of capital. A notable example of this came to my attention not so long ago. The plant in question was a textile mill and had available for its construction a certain definite sum of money, 12½ per cent of which would have been necessary for the establishment of its own power plant. After carefully considering the power question it was decided to purchase energy of the central station, with the result that the annual output was increased by nearly 15 per cent through the investment in productive manufacturing plant of an amount equivalent to that which would have been required for the construction of an isolated power plant.

In order roughly to estimate what advantages might have resulted, under average conditions, if central station energy had been adopted instead of isolated plants and if the construction cost of the latter had been invested in productive manufacturing plant, in the case of eleven selected industries in the United

States, the following table has been prepared. The figures given in this tabulation are for the year 1905 and are either directly taken or estimated from a combination of statistics found in Bulletins Nos. 57 and 88 of the U. S. Bureau of Census, relating respectively to manufactures and to power employed in the same. Referring to this table, the figures given in columns *A* to *E* inclusive are taken directly from the Government records, just referred to, while the values in colums *F* to *N* inclusive are estimated, from figures given in columns *A* to *E* inclusive, in the following manner: Column *F* gives the estimated amount of capital at present invested in isolated power plants, for the industries represented, and in order to be conservative was figured at the average cost of $65 per rated horse power employed, as found in column *D*. This figure is considered fair in view of the mixed character of the motive power used. Having ascertained the estimated capital invested in isolated plants, the estimated capital employed in productive manufacturing plant exclusive of power plant is given in column *G*, and is obtained by deducting the former quantity given in column *F* from the total invested capital as found in column *C*. Column *H* gives the net estimated return on capital invested in manufacturing plant, exclusive of isolated power plant, and is derived from the total value of products, and operating expenses as given in the census bulletins previously referred to, an allowance being made for depreciation in each case. By dividing the total of the products given in column *B* by the number of thousands of dollars of capital invested in productive manufacturing plant proper as given in column *G*, the figures in column *I* are derived, which show the estimated value of products for each $1,000 invested in productive manufacturing plant proper. By considering the amounts in column *F* (representing isolated plant construction costs) as invested in productive manufacturing plant proper, and applying the unit figures given in column *I*, the various estimated increases in the value of products, as given in column *J*, are obtained. Column *K* contains the values given in column *J* expressed as percentages of the total value of products given in column *B*. By applying the percentages of net return on capital invested in productive manufacturing plant, as given in column *H*, to the estimated amounts invested in isolated power plants as given in column *F*, the net return on such, if employed in productive manufacturing, is ascertained, and is given in column *L*. Column *M* gives the estimated number of horse power that may be considered as continuously active throughout a year of 8,760 hours. Finally, column *N* gives the estimated maximum average increase in price for each used horse power per year that various industries could afford to pay for purchased energy above the cost of isolated plant service, before exceeding the profit that would result from investing isolated power plant construction costs in productive manufacturing plant proper.

So much for the compilation and derivation of the figures used.

Upon glancing through the table some interesting points develop. It will be noted from column *D* that by far the most important industry of those considered, in the matter of aggregate rated horse power, is the iron and steel industry, and that this same industry is second in rated horse power per $1,000 of products, while the greatest such unit recorded is that for the paper and wood pulp industry, with nearly six horse power per $1,000 of products, the silk industry being the lowest in this respect, with hardly more than one-half horse power per $1,000 of products.

The final values given in column *N*, showing the estimated average margin that industrial plants of various types may allow between the cost of "home-made" and purchased energy, may at first sight seem to show rather erratic tendencies in the wide numerical range scheduled, but when it is remembered that these figures are susceptible to a number of modifying factors, peculiar to each industry, the seeming discrepancy is explained. For example, let us consider the two extremes shown in column *N*, the cotton goods industry, with the lowest margin of $8 per used horse power per year, and the lumber and timber products industry, which shows the greatest margin of $93 per used horsepower per year. Considering the former, it will be seen from the table that the cotton goods industry shows the least net return on the invested capital and this, coupled with the fact that the rated horse power requirements of this industry are not very large, results in a low earning power of isolated plant cost when invested in productive manufacturing plant. Reviewing the conditions responsible for the abnormally high figure of $93 margin in the case of lumber and timber products, from an inspection of the table it will be clear that while the rated horsepower requirement per $1,000 of products is practically the same for this industry as the figure for the cotton goods industry, the chief reason for the large margin in the former is found in the large net return on investment in productive manufacturing plant, coupled with the relatively small continuous use of rated horse power employed. In the iron and steel industry, while the rated horse power per $1,000 of products is second in order of importance, the low net return on the invested capital militates against a greater margin between the cost of purchased and "home-made" energy, the actual figure being $18 per used horse power per year, as given in column *N*, and while this figure is of substantial proportions it is noteworthy that it is next to the lowest in the list of industries considered. It is further notable that even the minimum figure given in column *N* is quite material and, while only averages are dealt with, the results arrived at in the table are strongly indicative of the importance, to those laying out new industrial undertakings, of carefully considering the imminent possibilities of increased outputs and resulting profits to be had through the investment of all available funds in productive manufacturing plant, made possible by the purchase of all electrical energy required from an outside cen-

Agric
Boots
Flour
Hosie
Iron a
Lumb
Paper
Cotto
Silk a
Wooll
Worst

tralized source, with an organization capable of intelligently handling energy supply problems with a maximum of advantage to the consumer.

Surely the advantages of central station service as enumerated above may have a monetary value, which may be such as to often render the net cost of such service very low when all the factors are given due weight. It is therefore apparent that the mere gross price per kilowatt-hour charged by a central station may be of secondary importance and is not always the controlling element in making a comparison between "home-made" and purchased energy.

P. R. Moses: In reply to a criticism of the diagrams of practise, the diagrams speak for themselves. They were not intended to "determine relative proportions" of "apparatus." They were designed as finger posts to point out the mutual dependence of the parts of the mechanical and electrical equipment of buildings and to show that with certain basic conditions, certain types of users and makers of steam and electricity would seem to be, *prima facie,* advisable.

How can it be an open question, economically speaking, whether it is advisable to install steam driven fans for indirect heating, when steam must be supplied for heating, in any event, and when it can be obtained from the exhaust of the engine driving the fan, thus doing two jobs instead of one?

As to the statement "that low efficiency and wasteful lighting is regarded as an element which does not disturb the overall efficiency of the isolated plant"—this is a fact which can hardly be disputed if the amount of steam at low temperature (215 deg. fahr. or less) required for heating, drying or evaporation processes is more than the amount which would be supplied by the wasteful engines operating the isolated plant. If we have to fill a reservoir from a water power at the rate of a thousand gallons a minute, and we put a waterwheel in the flow, if we only need the power available from 500 gallons a minute there could be no gain by installing a high-efficiency waterwheel. The same thing holds true of isolated plants, and it is rather surprising to have this questioned.

Curve 12 is typical of an office building *with* a restaurant and curve thirteen of an office building *without* a restaurant. This I believe was clearly shown in the original paper and the two curves were chosen particularly to show the effect of occupancy upon load. It is interesting to note that in the Trinity building the all-day load factor was only 37.6 per cent of the capacity of the sets under steam. It was to aid in avoiding such errors as this that the paper was presented, and it was hoped that other data of operation results would be presented showing average, maximum and night loads, which would aid future designers in planning their equipment to secure at least 75 per cent load factor at all times for sets operating. The paper sets forth clearly the reason for not including elevator swings,

because in modern plants these swings should be taken care of by a storage battery unless they are of such minor importance as to be carried by overload capacity. The criticism of the log sheets is beside the mark, as the paper clearly states that they were inserted merely to show sample *forms*.

Mr. Parker's discussion brings forth several points of interest and his suggestion that the data on building heating be reduced to a formula is an excellent one.

I have found, however, from experience, that a comparison of buildings similar in size, character, occupancy and location is more useful than attempting to derive the cost from a formula. One building may have textile manufacturing requiring little heat and another a series of studios requiring a lot of heat, one may be open twenty-four hours a day and another nine. Formulas could be derived to cover all cases, but the comparative method seems easier.

The discussion of installation costs per kilowatt capacity is based on an erroneous idea of the intent of this table. The cost given were intended merely to aid designers in preliminary estimates of costs, hence the items of cost of building and stock did not enter. Frequently these items must be considered, usually as an increment to the general cost—that is, the stack would be required anyway, but may have to be larger. Engine and boiler rooms will be needed but might be less extensive without a plant than with one. This is by no means always true, but sometimes.

The point about the reduced effect of marginal increase or decrease in production is well taken, and the facts stated have been strikingly borne out by the records of operating results in a number of plants where increased kilowatt-hour output resulted in a very much lower ratio of increase in fuel use.

The interesting discussion of the comparative saving derived from the use of tungsten light on central station and isolated plant service shows a saving nine times as great when using central station service as when using isolated plant service.

I cannot agree with Mr. Parker that this does not prove the corollary to be true, viz., that isolated plant service costs one-ninth as much as central station service under the conditions noted *for all increments of load*. That is, given a plant operating under stated conditions, additional load can be supplied at a comparatively slight increase in cost up to the limit of the plant capacity, because the increase in cost is confined to the costs of fuel and oil, and, even in these items, in a greatly decreased ratio.

The discussion by Mr. Martin requires no comment, except that it seems difficult to understand what repairs to heating system have to do with cost per kilowatt-hour. The item of depreciation seems confused with the item of repairs, otherwise it is hard to see how the neglect of the item of depreciation "well nigh resulted in the total shut-down of one of our largest office buildings."

As to Mr. Nichols' discussion, the statement in the original paper is quite correct, that if electricity is made on the premises the exhaust steam available points to an exhaust steam operated refrigerating plant. Whenever electricity is made on the premises, exhaust steam will be available from steam driven house, boiler and other pumps, besides those of the refrigerating plant; and where this exhaust is not sufficient and the refrigerating plant work is a large proportion of the total work, it would probably pay to design one of the electric units to operate a sufficiently high back-pressure to do the required refrigerating work because as long as all the temperature range and heat units are fully utilized it does not matter how much is used in making electricity and how much in refrigeration. The overall efficiency will be a maximum.

Referring to one criticism, the emphasis was laid on compactness and simplicity in connection with the discussion of the design, and the original paper clearly points to the fact that the chief advantage gained by these two qualities is reliability.

The criticism is made that "while the figures are represented, from the heading under which they appear, as being fuel and labor costs for heating, they actually cover, in at least fifty per cent of the cases cited, by the author's own admission, the cost of producing steam for other purposes than heating the building." The author clearly stated that these costs included steam for other purposes, and his intention was to present facts and figures representing actual conditions which could be compared with actual conditions in other installations.

Manufacturing buildings frequently—one might almost say generally—need steam for manufacturing. Of what use for comparison or estimate is a cost of heating only? The whole basic condition is changed at once and for intelligent estimate another building containing similar basic conditions must be used.

Mr. John W. Lieb, Jr., brings out a point of interest in a clear and direct manner. He considers that the author's practice, as described in the paper, of using steam pumps, etc., in buildings where electricity is purchased is not logical or justifiable.

The reason for the use of steam pumps, etc., is that in all the buildings where they are used there is a certain minimum amount of steam required all the year for hot-water heating, dryers and in some cases for refrigeration. The steam can be most efficiently supplied by first using it for pumping and it is for this reason that steam pumps and steam driven ventilating fans are employed. Boilers, it is true, must be operated at somewhat higher pressure than for heating purposes only, but it will be found that where an attempt is made to operate one boiler for heating a building, heating water, laundry dryers and other low temperature work, the result is invariably unsatisfactory because not only are different initial pressures required for these different purposes, but, what is of greater moment, the

terminal pressures at the outlets of the various steam-using parts of the plant are unequal, and all kinds of troubles result from the backing up of one set of returns into another.

Mr. Clarkson's discussion touches on one evil in isolated plant design—the installation of engines, etc., far too large for their work, "to take care of future possibilities." How much better to plan to care for the immediate future with a reasonable allowance for future expansion and leave space for additional apparatus as the demand increases. His note of the tendency of a consulting engineer to plan for possible future installation of a plant is interesting. Frequently this is the best plan to adopt, particularly in city buildings, if the renting and character of tenancy is not assured. If space is provided and if such apparatus and piping as is installed is planned with future plant in view the present omission is often the most advisable course to adopt.

I cannot agree with Mr. Clarkson as to internal combustion engines. Their performance when correctly designed and installed is remarkably good. They not only give excellent results under test—1¾ lb. of coal per kw-hr. is not unusual with engines of less than 300 h.p.—but what is far more important, their average operating record varies but little from their test performance. My confidence in their performance was such as to justify a recommendation of the installation of three 200-kw. producer gas engine driven dynamos in far off Porto Rico, where the ordinary labor is not our skilled type, and the results have justified fully the advice.

The cost of operation of the building mentioned in the paper would have been seriously increased by the substitution of an electric driven refrigerating plant and a low pressure boiler for heating and cooking. The cost of electricity for the 15-ton refrigerating plant operating about 6500 hours a year would have amounted to over $4000 a year, and the labor required would not have been decreased $500 a year and the fuel not over $1500, so that the annual operating cost would have been increased $2000 and the fuel cost would have been greater.

Mr. Clarence P. Fowler's discussion re-states many of the points first developed in Mr. Parker's paper* before the A. I. E. E. on Industrial Power, and is an exceedingly able plea for the use of central station service. I do not feel that a discussion of the comparative merits of central station and isolated plant service is in order, and in fact this subject has been exhaustively treated heretofore. The suggestion that the user of electricity who is also the purchaser from the central station should leave his problems to the central station is interesting, as it reverses the tried adage of *caveat emptor*—"let the buyer beware."

The lack of specialized knowledge in the design and operation of isolated plants is a great drawback and the fact that not a single figure or record of any value whatever has been added in the discussion of the paper indicates clearly the reason.

* *Comments on Fixed Costs in Industrial Power Plants*, by John C. Parker, PROCEEDINGS A.I.E.E., March 1911.

Engineers apparently have no data of operating results to give or else they regard them as knowledge which is so precious and so hard to gain as to be worthy of protection behind triple bars of steel. Why can we not have full discussion of operating results and presentation of the facts of isolated plant operation data on the heating of buildings. Hundreds of engineers throughout the country have these facts and yet they will not bring them forth.

Why? Because they are afraid that, where not controlled by uniform Public Service regulations, their figures will be used and a price fixed by the central station companies below their cost and *below the average cost of making and distributing the current.*

The supervising of private plants by the executive head of an industrial corporation mentioned in Mr. Fowler's discussion is a bogie. The extra supervision involved because of the electric generating plant is not to be separated from the supervision of the heating, and a compressing plant.

The really great argument in favor of central station service is ably developed by Mr. Fowler. It is the familiar cry of the old-time department store, "Cash." Wellington in his classical book on "The Location of Railways" says, "No expenditure, otherwise justifiable, is proper if it jeopardize the success of an enterprise as a whole." So it is with the question of installing a private plant or building a building or any part of a sales process which can be done without.

If the cash capital or credit is so limited that it will suffice only for a selling force then it is unwise to invest any capital in manufacturing. If the capital is sufficient to buy a manufacturing equipment but not a factory then it is unwise to build a building —much better lease one until the enterprise is established. So, if a manufacturer has barely enough money and credit to allow him to complete his factory and start his selling then the best thing he can do is either to use the credit of the central station company, even if he pays excessive interest on the cost of the electric plant in the shape of excessive cost of current, or take the alternative which is now possible. He can purchase his power plant on the instalment plan, avoiding the necessity of taking the capital out of his business.

When he buys a power plant on this basis, giving notes and mortgage on the plant as security, he only pays the legal rate of interest and can use his cash capital and his bank credit in his business. The whole argument that the power plant cost could be better used in the purchaser's business is of no real substance. The interesting statistical table given by Mr. Fowler fail to be of value because its premise is unsound, that a purchaser must either take money out of his business or buy central station service. In fact, he frequently does neither.

I have reserved my closure on Mr. William's discussion of the paper to the last. Mr. Williams' discussion should be carefully considered. The admitted figures of one of the buildings on

Fifth Avenue, New York City, he states, show that "a gross annual saving of about $11,500 was effected," of which the consulting engineer received one-third. The saving was $11,500 out of a total cost of central station service of about $19,000 for the original building and one afterward supplied from it, a saving of about 60 per cent. The consulting engineer—I regret to make this statement but it is necessary for a clear understanding—only gets his one-third because he invested three-eighths of the cost of the installation.

To the consumption of current in the original building was added that of the building afterward supplied from it, this would not have effected a saving, as Mr. Williams puts it, of $3,000 a year. The saving, even under the inequitable rate making method based on quantitative use alone, would have been only $1500. *En passant*, the absurdity of such a basis for rate making may be noted, although not germane to the subject—here are two buildings with nothing changed except that there is one contract instead of two, and, presto the cost drops $1500 a year, or nearly 10 per cent.

The plant did not cost $30,000, as Mr. Williams stated. It cost about $22,000, including all changes, installation of a storage battery, water weigher, CO_2 recorder, etc., so even allowing 15 per cent the difference is *not* "automatically and immediately wiped out."

Mr. Williams then makes the surprising statement that the whole investment in plant should be wiped out "the first year" and he adds that he does not think this premise can be fairly questioned—nor do I. The assumption is really too startling and its best answer is its own re-statement. However, the plant is still running and earning 60 per cent and will probably do better next year.

Mr. Williams next refers to the Equitable fire and forgot to mention that the supposed cause of the fire was the *lighting of the gas*, because the private plant was not being operated in the early morning, and the lighting supply was being obtained from a central station.

The criticism with which Mr. Williams closes his discussion—the reference to the omission of costs of excavation, etc.—is sometimes, but not often, well founded. Usually, space is left in a well-designed building for possible installation of a private power plant or other machinery impossible to foresee at the time of erection, and the installation of the engine and dynamos does not involve additional expense, hence it should not be charged to the private plant. In other cases this is not true, and in such instances—as where a vault has been especially opened under a sidewalk—the whole cost should be, and usually is, charged.

I cannot follow the example of the twelve-story and the eighteen story building, but I do know of one twelve-story office building where an isolated plant reduced operating expenses nearly $4000 a year and earned over 30 per cent on its cost.

DISCUSSION ON "SOME PROBLEMS OF HIGH-VOLTAGE TRANSMISSIONS" (STEINMETZ) AND "CHARACTERISTICS OF PROTECTIVE RELAYS" (HEWLETT). NEW YORK, MARCH 8, 1912. (SEE PROCEEDINGS FOR MARCH, 1912.)

(*Subject to final revision for the Transactions*)

David B. Rushmore: I want to say a few words about some of the new things in power transmission. President Dunn mentioned the waterpower part of it—water is often spoken of as "white coal." We are now coming to a situation of black water, that is, we are going beyond the development of waterpowers for power transmission, and one of the installations under consideration, which is just being put in, is one of the most interesting phases of the present power transmission. The Lehigh Coal and Navigation Company, the oldest of the anthracite companies in the Pennsylvania field, is just in the process of installing the first steam station in the East for purely power transmission purposes. They are going to be within easy transmission distance of both New York and Philadelphia, and ultimately will have a steam turbine plant of 120,000 kw., as their plans are at present. In future they may exceed that capacity. Their plans are to transmit power, for local distribution largely, for cement mills at first, and also, presumably, for the lighting of the towns through which they will pass, and possibly reaching into New York or Philadelphia, or both.

There is now in process of construction on the Mississippi river at Keokuk, Iowa, a 400,000-h.p. plant to develop the water power and naturally to reach out in all directions and furnish the lighting and power for that neighborhood.

In other parts of the central west there are under actual construction at the present time a number of plants for transmitting power from coal mines, burning the coal and transmitting the power, combining in one system a large number of smaller lighting and power plants. Very soon there is to be in operation in Virginia a waterpower plant which is going to sell electric power to the Pocohontas coal field, which is a very unusual situation. There has just been placed in operation in Michigan a plant to operate at 140,000 volts, and there is under consideration, in the farther west, a plant which may operate at a very much higher voltage than that. So that power transmission at present, in the art of transmission, in the development of the anthracite fields (and I may add that the other anthracite companies are watching this development with the greatest of interest because selling their power in that form has many attractive features, and it is not unlikely that we may have a number of other developments in this field)—in the kind, in the voltage, in the distance, the high-voltage power transmission, (not the question of high-voltage power distribution in large distribution circuits as in the Ontario hydroelectric system,) is coming more and more under consideration, and also the question which we must face at some time, the State control of power distribution, as in Ontario the State will sell power to municipalities. That

borders on a question of great importance to a large number of men. Some of you know that the Ferris bill at Albany proposes to do this.

There is one gentleman here this evening who has very much more experience in actual power transmission work than most of the men in the Institute, having been connected with the early development in Utah of the Telluride Power Company, which was one of the earliest of the large transmission companies, and afterward he served as operating manager of the Central Colorado, and now he is in St. Louis preparing to receive a large proportion of the 400,000 h.p. which is being developed on the Mississippi at Keokuk. I refer to Mr. Ruffner, and I am sure it would be very interesting to the Institute members if he could be induced to tell something of his experience in this work.

C. S. Ruffner: The general problems of trunk transmission systems are those which are growing out of the distributing systems of lower voltage, and it seems that we must shortly face the necessity of so providing means of control and operation on large inter-connected high-voltage systems of large power that those systems may be operated with the same reliability and satisfaction with which the lower voltage and lower capacity circuits have heretofore been operated.

That seems not only to be a question of degree in voltage and power concerned, but in some measure a question of the methods of connections and details of operation. Particularly, I believe that the features brought out by Mr. Hewlett's paper tonight are the ones on which the greater part of the success of any high-voltage power system must depend.

Unfortunately the larger systems now in operation seem to have been the result of more or less gradual growth of various systems with very little harmony in their original design, which being connected together, operated under adverse circumstances. Under these circumstances the questions of relays and control have become of the greatest importance. If such systems were possible of immediate development in their final stage, relays would be not only disadvantageous, perhaps, but a distinct nuisance, and I am sure Mr. Hewlett then would not recommend their use in general. Most of the relays I have been acquainted with have been relays installed in the hope that they might accomplish some good function and were operated either by disconnecting from the control circuit or plugging their connection by some means. That, I think, should not be taken as a criticism of the proper use of relays, but rather an expression of the belief that they have been used too indiscriminately and in places where they should not have been used. Perhaps, to counteract the impression that statement may have made, I owe to Mr. Hewlett to say that we have used in Colorado his balanced relay described in the paper this evening, with excellent results, when nothing else seemed to be able to insure satisfactory service. In that case two power stations were feeding one

substation from a single line each, that is, the two lines came to one point, and from that substation the lower voltage power was delivered to a synchronous system, the system including lighting service, induction motors, synchronous motors, and such apparatus as is used for general factory and residence lighting. A great deal of trouble was experienced on the transmission circuits of that plant, but after installing this equipment of relays their action was made accurate enough so that in several cases they disconnected the defective line, allowing service to be continued from the remaining good line, in one case, from a station which at the time of the occurrence had been running as a synchronous motor with no water on the waterwheel, and disconnected that defective line promptly enough and acted in partnership with the waterwheel governor so that the synchronous load was not interrupted. I think that is as much as could be asked of any relay, and it was necessary to use relays in that situation to obtain any satisfactory service at all.

There is one other feature that might be of interest referring to the statement made in Dr. Steinmetz's paper, on the action of suspension insulators, of atmospheric disturbances being manifested particularly at the insulator closest to the transmission line wire.

I recall one system in which some two hundred cases of lightning disturbance occurred during one season. In all the cases where the disturbance affected the transmission line insulators, the disk nearest the conductor was damaged, in most of the cases punctured, and in about twenty-five per cent of the cases in which the insulators were damaged, the insulator nearest the grounded structure suffered in the ensuing arc. None of these were punctured. This shows very distinctly the effect of the high frequency disturbances on the puncturing and failure of transmission line insulators. It indicates, apparently, that we might insulate a line too thoroughly, for ordinary purposes, and still could not obtain satisfactory service at high frequency.

I have seen a great many cases of transmission line trouble, originating in line and apparatus, and being manifested in breakdowns at different places in the circuit, but I have never yet seen a case of failure of any of the connected apparatus which did not seem to be entirely due to the localization of potential due to the point of high frequency and reactance. Perhaps that statement is a little too broad, but I can recall no occurrence of an arc, due to the failure of any apparatus, or over-voltage, which was not very clearly explained by the presence of high frequency combined with the change of circuit constants at the point of breakdown.

F. W. Peek, Jr.: I think in connection with Dr. Steinmetz's paper it is interesting to look back into the past, and then forward into the future, to see how past difficulties compare with present difficulties, how apparent limitations of the past compare with apparent limitations of the future. What makes

me think of this is that the other day I came across, quite accidentally, an old book of letters by a very prominent engineer—it was not such an old book either, measured in time, but old measured by engineering progress. The writer states in one letter that an operating transformer had actually been built that could stand 15,000 volts, and it was hoped that ultimately a transformer could be built to operate successfully at 20,000 volts.

The apparatus at that time was the limiting feature of transmission. Voltages went up by leaps and bounds, and transformers were shortly thereafter operating practically at voltages of from 50,000 to 60,000. At this stage the pin type insulator began to give trouble, so, naturally the suspension insulator was invented. Voltages then jumped up to 100,000, and another trouble appeared, or what seemed to be a trouble or limiting feature, that is, corona. This led to investigations of corona losses, and it now appears that we still have some margin in the matter of corona limit; for instance, power could be transmitted at 200,000 volts with a conductor about one inch in diameter with 12 to 15 feet spacing.

With long lines and high voltages other troubles appear; as an example, suppose we take a line, say, 200 miles long, with a voltage of 140,000. The capacity current may equal the total load current of the whole station. This will mean trouble unless some method is adopted that will take care of this heavy leading current, or the generator units are properly arranged as to size. If part of the load is supplied by part of the generator units and the load is suddenly lost, these units may be over loaded by the capacity current. Another emergency to be provided against is the rise in voltage at the receiving end (due to capacity current through reactance) when the load is suddenly thrown off. Taking a practical instance, after the comparatively small lighting load is taken on in the evening, the heavy factory loads go off; over-voltage is put on the lamps. Fortunately, the effect of capacity current can generally be well taken care of by shunted synchronous reactance.

Now, it is rather interesting, for the moment, to look forward into the future and perhaps ask a question—What will actually be the limiting voltage of power transmission, or limiting distance? Will it really be due to the loss of energy into the air by corona, the line insulator, the apparatus, or will it be an electrical feature after all? Will it not rather be, with some few exceptions, an economic or natural feature? For instance, the power naturally concentrated at a given point, as in a waterfall, will generally be exceeded by the demand before the distance becomes so great that it is necessary to use voltages above the electrical limit.

Percy H. Thomas: In the early days of power transmission the assumption was that the length of line that would be financially justifiable would limit maximum voltage, the theory being

that a voltage as low as would carry the load the requisite distance should be used. At the present time, however, high voltage is required, not necessarily for long distance transmission, but for large power transmission. This high voltage serves, in some degree, to produce leading current to balance the lagging current of a general load. From this point of view you will see there is an advantage in using from 150,000 to 200,000 volts, if possible, if there are to be stations of a half million horse power. Corona losses at 200,000 volts will undoubtedly be taken care of, as have all the other difficulties that have come up in high-tension transmission work.

It has just been said that there was a time when it was questionable whether 15,000-volt transformers could be made to operate. I happen to remember a case where some 10,000-volt transformers were ordered and promised, and some were built. These were oil-insulated, but no solid insulating material was used in addition to the oil, and the transformers were found, when tested, to stand only something like one-third normal voltage, if I remember correctly. They were started up and ran at as high voltage as they would stand, and then they were taken out of the oil and examined, and then put in good shape and put in again and the voltage again applied and the transformers run a little longer. Soon a voltage as high as half normal voltage could be used before they broke down. They were examined again and found not to be injured, and were put in oil again, and after having been run thus a half-dozen times, they finally got to a point where they would operate at normal potential, 10,000 volts. They were finally taken out and put in service and did good work. It was not understood at that time that it was necessary to dry transformer oil. As they were run and operated they got hot, and with patience the tester unconsciously succeeded in getting the oil dried out. There was no harm done by the numerous breakdowns because there was no solid material between coils, and the oil space alone was relied on for insulation. Transformer construction has progressed somewhat since that time.

Dr. Steinmetz pointed out one of the weaknesses of the suspension type insulator (the multiple unit insulator), that is important to bear in mind. He calls attention to the fact that high frequency disturbances are more apt to produce the concentration of potential than ordinary 60-cycle voltages. This is true but yet you must all remember that the capacity of each insulator in the series, and the capacity of each to ground, both vary with the frequency. The effect of raising the frequency is not to change the relation of the capacity of the insulators as units in the series to the capacity of each insulator to ground, but high frequency gives the capacity currents, as distinct from insulator leakage current, the power to determine the voltage.

Dr. Steinmetz has also made certain comments here in his paper on an old subject that used to interest me very much and

still does, and that is the matter of internal surges within transformer windings. The action of the surging on a transmission line is relatively easily understood. This is because the constants of the transmission line are uniformly distributed— the capacity per mile at one point is the same as the capacity per mile at another point. Similarly with the inductance. But within a transformer winding the capacity per foot of wire and the inductance pei foot of wire vary in different parts of the transformer and change between the outer part of the coil and the inner part of the coil, between the line coil and the outside coil. There is also capacity between the high-tension coils on their surfaces opposite the low-tension coils, and opposite the core. The net result is that the condition of uniformly distributed inductance and capacity does not exist when the wire is wound into coil on a transformer, and therefore none of the ordinary formulas for line conditions apply to the transformer; only empirical methods can be used.

Dr. Steinmetz is right in saying that a high-potential surge consisting of a single wave approaching from a line will enter to some distance into a transformer. I am inclined to think however, that it is not a symmetrically preserved wave which passes along the winding from the terminal to the interior of the transformer, but rather that the rush of current in proceeding part way into the outer coil, which it first reaches, induces in the adjacent coils a similar rush of current just as one transformer coil induces potential in another. Usually there are two or more high-tension transformer coils close together. You cannot produce a disturbance in one without producing by electromagnetic induction a disturbance in the other, and I am inclined to think that that is the real reason why the surge striking one coil will produce a surge which will be found in the next or subsequent coil.

I made some experiments some years ago to study this matter. I worked on a transformer with ten high-tension coils very thin and very deep, arranged close together, where the conditions for mutual inductance were particularly favorable, and I traced the concentration of potential on the outer coil, which was struck by a static disturbance produced by an arc, and the effect was very marked on the first few turns, less in the next, and so on until it became normal voltage, taking the whole coil into consideration. The next coil had taps brought out permitting the measurement of the concentration of voltages there, and there were concentrated discharges on the turns of the inner coil, much less in magnitude, to correspond exactly with the concentration on the outer coil, and these induced currents from an electromagnetic field existing in the space about the coils—the transformer primary (first coil) induced current in the transformer secondary (second coil).

A. E. Kennelly: We are all indebted to Dr. Steinmetz for making so clear the peculiar differentiating conditions that occur

in a string of suspension insulators, so that we may look upon these, in the future, from an electrical standpoint, as a sort of inverted Chinese pagoda. It is also very interesting to notice the effect of increasing voltages upon disturbances inside the transformer. We used to think that with one outer door we could limit all the high frequency disturbances to the outside of a transformer, and keep every thing safe indoors. Now we find that we must not only barricade the stairs as well as the doors, to keep high frequency disturbances from invading, but that we must also supply some kind of a fire escape.

In regard to that part of Dr. Steinmetz's paper which deals with the rise of voltage on long distance lines, we have at Harvard an artificial long distance transmission line which is 500 miles long, three-phase, or 1500 miles single-phase, probably the longest of its kind which has yet been built. It is very easy to make electrical measurements on such a line, because there are no difficulties with lightning, switching, synchronizing, or load variation. The advantage of such a line is that you can do on it in an hour what on an actual, regular transmission line it would take a week to accomplish, in the way of making observations and switching.

We have taken 650 miles of the artificial line, as being representative of the longest line likely to be produced in the near future, and have operated that at various frequencies, from 25 cycles per second up to over 400 cycles per second, and the differences produced are very marked. It is difficult to keep the frequency sufficiently pure. If there are harmonics in the impressed e.m.f., complications enter into the results, but if the frequency of the impressed e.m.f. can be kept very nearly pure, definite and easily verified observations are obtainable.

The results are being calculated and worked up for a paper that we hope to present at a later date.

In general, we find that at 60 cycles per second and 1000 km. or 621 miles of line, the rise of voltage at the distant end, with a sinusoidal e.m.f. impressed on the home end, is about 75 per cent, so that if you have 100,000 volts at the initial end you would have 175,000 on the distant end, without load. As the load is put on, there is a tendency to bring that excessive voltage down, but nevertheless, at what may be called rated load, there is still great difficulty in regulation, as Dr. Steinmetz's paper describes. If, however, we take 25 cycles per second, the rise of pressure is only 10 per cent instead of 75 per cent. The open end rise of voltage is therefore relatively negligible on 25 cycles per second, whereas it would be very serious, indeed, on 66 cycles per second with no magnetic reactance taps at intermediate stations.

When we come, however, to 400 cycles per second, we may get a rise of voltage of ten times the voltage applied. With a sevenfold frequency or a 420-cycle harmonic impressed on top of the 60-cycle generator, you can see that a 10 per cent ripple would

be able to produce something like 100 per cent increase in voltage, compounded at right angles to, or by " crab addition " to the fundamental; that is to say, 10 times 10 per cent would give 100 per cent, at right angles, or perpendicular to the regular pressure and that would mean 41 per cent increase by voltmeter. So there is good experimental reason to believe that a distinct rise in voltage at the distant end of the transmission line, on open circuit, may be due to the effect of ripples of a higher frequency.

The subject is very interesting and practical; but it is necessary to go slowly so as to check up each particular set of observations by calculation. One can secure more observations on the artificial line in an hour than can be worked out in a fortnight. Without hyperbolic functions, it would be hopeless.

A. S. McAllister: The inaccuracy of the term " reverse-current " relay is apparent when one considers that the relay is used in a circuit in which the current always reverses from 50 to 120 times per second. In no respect can the device be called a reverse-current relay. What reverses is the flow of energy, and the device is, therefore, a " reverse-power " relay. The incorrect term is in common use by the manufacturers, but it should not be permitted to appear in the TRANSACTIONS of the Institute.

Farley Osgood: First, I want to thank Dr. Kennelly for his new term " crab-addition." It is most original and unique, and quite like him.

I have very little to say in the nature of a direct discussion of either of these papers. I might give a word of caution, however, as an operating engineer, in the matter of the care of the relays. I do not think that Mr. Hewlett warned us quite enough as to this point. Unquestionably, the proper operation of this bit of apparatus depends very largely on its being carefully watched, carefully tested, and most important of all, carefully and often cleaned. The great trouble with relays is that they are such a comfort that when they work well we very largely neglect them, and leave them to go their way without any attention. The relay is a good friend, in good condition; but it is the worst friend we have, when it is in bad condition. A set of instructions properly drawn up, covering the periodic cleaning and testing of relays, should be enforced in any operating company; and the man in charge of the operation should insist, not only that the reports be sent to the chief at the specified time, but that the report should be fairly and honestly filled out by the men who do the work, stating that the work is done. Unless we help the designers of the relays in doing what they tell us we must do, there is no reason in the world for us to expect that the apparatus will serve our purpose, and I assure you that it will not.

C. O. Mailloux: The President has called attention to one of my early sins. I plead guilty to being one of the original inventors—I even think I was the *first* original inventor—of the

automatic electromagnetic circuit breaker. I was its sponsor, and its wet nurse, and I assure you it was a very ticklish and troublesome task. However, it survived, and it quickly made a reputation, largely in the hands of other foster parents, in other words, various manufacturing concerns promptly appropriated it, incidentally without giving any credit or any remuneration to the original inventor in spite of the broad patent which the Patent Office granted him for the invention twenty odd years ago. But I survived that, fortunately, and so did the circuit-breaker, and it has proved a very useful and practical device.

Now, the circuit-breaker as I first conceived it was a relay; it was nothing more than an adaptation of the relay. The first circuit breaker which I invented, and which I may say, incidentally, was first used on the first electric car which ran in New York City (a storage battery car), in 1887, was a "relay" circuit-breaker. My first attempt failed, because it followed too closely the original idea of the telegraph relay, but one idea led to another and eventually something else was added to the idea of the relay and in due course, a working device was produced. It may be said that necessity was the mother of invention in this case. In those pioneer days of electric traction, a motorman often used up his stock of extra fuses before the car returned to the starting point. My own personal experience in improvising fuses made up of bits of copper wire, at the most inconvenient times and places, was what made me think of using a *relay* to control a *switch*.

While I suppose that every one in the electrical business has had more or less experience with relays, none of us have had as much experience as those who have seen the relay at work and have dealt with it in telegraphy. Our president, Mr. Dunn, and our past-president, Dr. Kennelly, are both experts in telegraphic engineering, and they could tell us a great deal about the virtues and qualities of the relay in telegraphic work. If there is any device which is really accurate and satisfactory, and which has the smallest percentage of error of any piece of apparatus, it is probably the telegraph relay. When one considers the number of "clicks" it makes in a year, and the very small percentage of failures which it makes of its own accord (that is, eliminating the errors due to the operator), one must admit that the telegraph relay is a very perfect piece of apparatus.

Now, when one sees the service it has rendered in telegraphy, one may well ask why it cannot render equal service in other branches. We know that it has done it in railroad signaling, for instance, in automatic railroad signaling, a field in which it has rendered a great deal of very useful service. In the operation of automatic devices in connection with central station appliances the relay has given some good service, but, very small, I think, in comparison with what it is destined to render.

My experience with the relay, as applied in certain stations,

has been characterized by some of those experiences which were referred to by the first speaker. As one of the first inventors, if not the original inventor, of the switch-controlling relay, I have always had a fondness for using the relay; and I was one of the first men to attempt to use it in connection with high-tension work. This was some years ago; and, I must say that it worked most often and best when it was cut out of the circuit, as the other speaker said. It was usually found most reliable when there was an attendant to watch the apparatus and cut out the circuit if he heard the transformers roar too loud.

In spite of the fact that the relays would get out of order, and were, in some respects unreliable devices, which required a great deal of cleaning and attention and testing, I never entirely lost faith in them. I have always believed in them and I believe now that they have a great future. I have always believed that we can, by their means, do a great deal that we now depend on human intelligence to do. I believe the relay is destined to play a very important part and we are only just beginning to see its development.

The task of presenting the characteristics of relays could not have been entrusted to a better man than Mr. Hewlett, who is known to be one of the most experienced men in connection with the equipment of a power house in so far as the apparatus which is requisite for the regulation and control of the circuits is concerned. Those of us who have had occasion to deal with him and to find out what he knows or what he can suggest are well satisfied that the problem could not be placed in better hands, and I know that in his hands it will undergo a process of development that will eventually give us far better results than we obtain now, though even now we are beginning to obtain quite satisfactory results.

The paper of Dr. Steinmetz, especially, is one of those papers which may be said to fill one with a number of emotions and feelings because it brings to us in condensed form very many interesting facts and phenomena which most of us would never have surmised could possibly exist even a few years ago, and which, nevertheless, as we see, play a very important part in the possibilities of high tension and long distance transmission. We find placed before us in intelligible form certain electrical phenomena with which we were all acquainted in their physical manifestations; for instance, the reflection of the wave, which is perfectly familiar to us as a phenomenon in optics, but which is not so easily grasped when we try to deal with it as an electrical phenomenon. The interesting facts to which Dr. Steinmetz calls attention, I think, are of the greatest significance and importance, and I am very glad indeed that there has been such an interesting discussion of them. I believe that the paper is one that will be very useful by the suggestions it contains and the realization which it brings to the mind of important facts that we had before ignored.

C. C. Badeau (by letter): The object of this discussion is to call attention to the very important point that besides selecting the proper type of curve for the proper protection of a system, extreme accuracy of the relays producing this curve is absolutely necessary in order to get satisfactory operation, as I believe more trouble is caused by the inaccuracy of relays than by selecting a relay with the improper form of curve, and anything in the relay field which would tend to make relays more dependable and accurate should be welcomed.

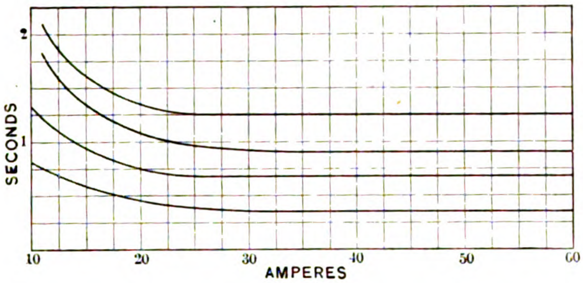


FIG. 1.

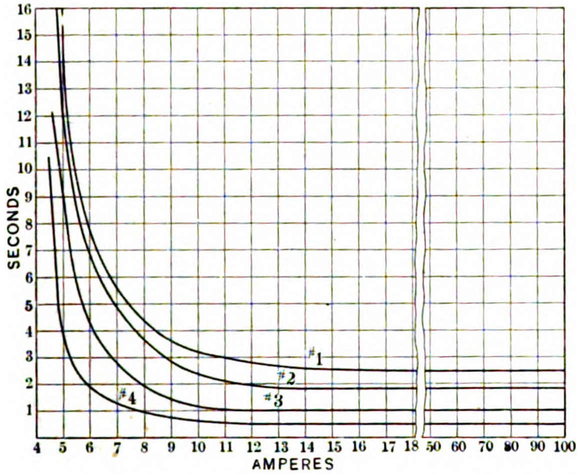


FIG. 1A.

Some relay curves which differ slightly from those shown by Mr. Hewlett in his article are presented herewith. It will be noted that in Fig. 1 of this discussion the relay curves do not become parallel until 30 amperes is reached, that is, the action below 30 amperes is inverse and above 30 amperes is definite.

The curves produced by this relay also differ from those shown by Mr. Hewlett, as in all of the curves shown in Mr. Hewlett's

article, except Fig. 2, the lines converge and tend to instantaneous operation, and a severe short circuit will destroy the selective action of relays set in this fashion. Mr. Hewlett has carried his curves out to 60 amperes, which is only twelve times full load current. Forty and fifty times full load current is not at all unusual on heavy short circuits, and with this amount of current selective action, with relays which present such curves as shown in Mr. Hewlett's paper, is destroyed.

These are the times when selective action is required, and, therefore, the type of curve selected should be one in which, after the relay operates in a predetermined time, it cannot operate any quicker no matter how much current is passed through it. Relays having these characteristics—both as regards accuracy and curve—are now on the market and in use.

Charles W. Stone: There are two or three points involved in Dr. Steinmetz's paper to which I would draw attention. I think the main feature of this paper is the question of distributive voltages over the different disks in forming a string of insulators.

What Mr. Peek has said is a point that we may think a great deal more about a few years hence, and that is, that before we get to the economical limits, as far as electrical apparatus is concerned, we may reach the other limit; that is, the development of power load may be too slow to keep pace with the industrial development, and consequently, before we are able to reach out into a distance so great as to make it impossible to use the present type of construction, we will have a larger field for the market near at hand than we can supply.

The figures given by Dr. Kennelly are extremely interesting, in regard to experimental transmission lines, and they are exactly in accord with the figures we have arrived at in connection with small transmission line of about 150 miles which has been built and installed in Union College in Schenectady.

The question of frequency has a very great effect upon the ultimate rise in voltage at the end of a transmission line, but I do not think it has been quite realized, in quantitative figures, what that comparison was.

I think that one thing that Mr. Thomas brought out in connection with the internal surges in the transformer perhaps may be misunderstood. I agree with what he said, as far as it went, but I think it applies principally to surges which have been started outside of the transformer. I think there are other surges that start inside the transformer, that are blanketted out by outside devices. and from those surges we have no means of protection at present.

E. M. Hewlett: Mr. McAllister brought up the point of the names of relays covering different functions, and I think it was an excellent point. We would like help on that point. It is hard to find descriptive names that seem to cover the different types and details of relays, and if any one can give us any suggestions

along this line, I personally would be very glad to use them, and we will see what we can work out as the best names for different circuits. I think that is a matter the Institute might consider and assign suitable terminology.

G. A. Burnham (communicated after adjournment): The subject of protective relays has been given serious consideration by engineers of late, and it is certainly a topic in which those concerned in the generation and distribution of electrical energy should be vitally interested.

As Mr. Hewlett has well pointed out in his paper this evening, practically no type of relay will meet all conditions arising, even in the simple distribution, and the selection of relays for the protection of the complex interconnected network of our modern large capacity stations requires careful study.

In speaking of protective relays we naturally associate them with the opening of a circuit breaker in order to relieve a system of some abnormal condition. On the contrary, it is as much the duty of the relay to prevent the breakers from opening in order to maintain continuity of service.

The selection of a relay should not be determined entirely by the curve of its characteristics, although we must admit that the shape of the curve is of vital importance. I believe that accuracy and permanency should have at least as much bearing as the shape of the curve and should be the first consideration in the determination of protective relays, especially for selective operation of circuit breakers. It is not so important that relays should be extremely accurate on moderate overloads, but on short-circuit values of the current of, say, eight to ten times full load, the error should not exceed 0.1 sec.; in fact, recent developments have produced relays so designed that with a current in excess of twice full-load current the error in operation is negligible. This extreme accuracy is of importance in that it really reduces the total time of operation of the circuit breaker and relay, and it appears that with a relay of this type one-half second is really more time than is needed. For instance, if we assume 0.6 sec. for switch operation with two relays only, the total time, with one-half second setting between relays on the occurrence of a short circuit of, say, twelve to fifteen times full-load current, would be 1.6 seconds, which certainly is not desirable where a relatively large generator capacity is connected to the busbar. If the relays are set for one-quarter-second selection, the total time becomes 1.1 sec., or, in other words, the system is relieved of abnormal stresses approximately 40 per cent more quickly than with one-half-second settings. This is certainly of importance where synchronous apparatus is employed.

With extreme accuracy a relay having a curve the first part of which is inverse up to a point, say of four or five times full-load current and definite thereafter, irrespective of the value of the current, is desirable, as it tends towards continuity of

service and still affords protection to the apparatus and cable system. In view of the tendency towards the use of power reactances to limit the possible short-circuit current to twelve or fourteen times normal, it appears that this type of curve should appeal to the operating engineer.

Another feature of extreme importance in time limit protective devices is the resetting feature of the relay. A relay should reset on at least 75 to 80 per cent of its minimum setting, and the circuit closing contacts should instantly resume their original position.

Regarding Mr. Hewlett's statement in connection with the protection of separate feeders by the use of circuit breakers having a low rupturing capacity installed at the various distribution points or substations, and a master switch of relatively high capacity located at the main station, so arranged that a short circuit in excess of the rupturing capacity of the small switches would result in locking them and allowing the high capacity breaker to open the circuit, it apparently is a step in the wrong direction as far as continuity of service is concerned.

It appears to me that in large central stations the matter of protection is really decided by two factors—so-called short-circuit interruptions and continuity of service—and that the matter of moderate overloads is something which the switchboard attendant could control. This being the case, it appears that little advantage could be gained in having a circuit breaker at the substations or distribution points which was only sufficient to open moderate overloads, and this advantage would be more than overbalanced by having the large capacity breaker interrupt the service of all distributing points on that particular feeder. In other words, we would really have a feeder which has no protection from short circuits except the main switch at the main station and in every event interrupting the entire service on the feeder. It does not appear to me that such an arrangement would meet with the approval of operating engineers.

E. A. Lof (communicated after adjournment): The protection of life and apparatus in connection with the maintenance of an uninterrupted service is a problem of utmost importance in any engineering undertaking. This is especially true in the present large electric power developments, which now mostly reach a capacity far beyond manual control. The expensive machinery and apparatus used in modern central stations and long distance high-tension transmissions makes it absolutely necessary to provide reliable automatic means for disconnecting generating units, transformers, transmission lines and distributing feeders at certain critical moments, both for the protection of the apparatus itself and for the maintenance of an uninterrupted and successful operation of the system.

The problem of protecting our power systems against shutdowns is therefore nowadays being given most careful atten-

tion and all of our modern plants are equipped with automatic protective devices to meet almost all conditions of service. These conditions naturally vary greatly in different systems and a careful study must be made in each particular case to determine the most effective protection for the system in question. The following discussion of the relay applications to the systems most generally met with in our long distance transmissions may, therefore, be of benefit to some.

Fig. 1 represents the very simplest transmission system consisting merely of one generator and step-up transformer, a single transmission line and step-down transformer. It is evident that the only protection which would be required for this system is an

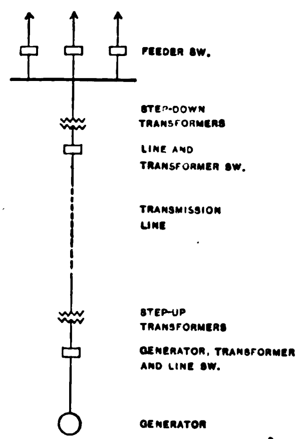


FIG. 1.

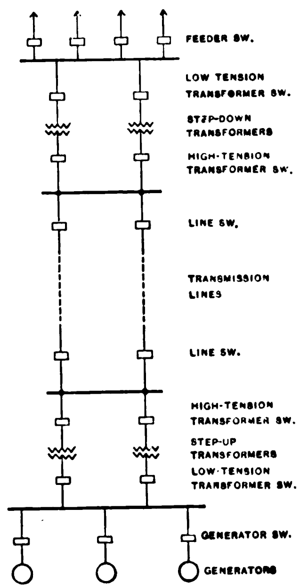


FIG. 2.

automatic generator switch. This should preferably be provided with the time limit relay, either of inverse or definite action, so as to prevent tripping of the switch on momentary short circuits such as the swinging together of the line wires, etc.

The substation switch is not absolutely required, and if provided it need not be automatic. In certain cases, however, it may be advisable to make this switch automatic also. Its time limit relay should then be set lower than the relay in the main station, so that a short circuit, etc., in the substation would simply trip this switch and thus confine the trouble to the substation.

The switches for the distributing feeders should, of course, be provided with instantaneous relays, so as to immediately disconnect the feeder in which trouble occurs, without shutting down the rest of the system.

Fig. 2 represents a diagram of a system consisting of three generators, two step-up and step-down transformer banks and two parallel transmission lines. A low-tension bus is necessary on account of the different number of generators and transformers. A high-tension bus should also preferably be provided so as to insure a satisfactory division of the load between the transformer banks. The generator switches in systems of this kind are often of the non-automatic type; the reason given by the advocates of this practise being, as stated in Mr. Hewlett's paper, the importance of keeping the generators in service in order to secure the most reliable operation, and the improbability of trouble between the generators and the bus-bars. The ability of alternating-current generators to stand a short circuit for some time will permit the operators to open the switches before any damage to the generators has been done. It seems, however, that it would be much safer to make these switches automatic, in which case the relays should be of definite time limit type, set very high. Reverse-current relays can also be installed. On a short circuit in one of the generators the current in this circuit will naturally reverse, causing the relay to instantaneously open the switch, thus entirely disconnecting the damaged generator from the system and preventing the other generators from feeding into the short circuit. The objection to this type of relay is, however, that on short circuits it will practically act as an instantaneous overload relay, and may cause opening of all the generator switches, and thus a shut-down of the entire system.

For protecting the two transformer banks, oil switches should be installed on either side. In case of trouble in one bank selective action should be provided, so that the injured bank can be disconnected immediately without interrupting the other. This can be accomplished by means of instantaneous differential relays. This relay consists of two coils connected to current transformers in either side of the transformer bank. Ordinarily the effect of one coil neutralizes that of the other, but on a reversal of current through one of the coils, each coil assists the other in operating the relay plunger, thus instantaneously opening both the high and low-tension transformer switches.

This method, however, gives no protection against overload. If this is required, inverse time limit relays are installed for the low-tension transformer switches and instantaneous differential balance relays for the high-tension switches. On a short circuit in one of the banks, the relay for its high-tension switch will then act on the reversal of the current and instantly open the switch, at the same time locking the relay of the other high-tension transformer switch, thus preventing it from opening on over-

load. The low-tension switch of the injured bank thereafter opens, thus selectively disconnecting the faulty bank. It is evident that inverse time limit relays for all the switches would not insure a selective operation, as the current through all the relays would have approximately the same value, thus causing all the switches to trip simultaneously.

The protection of the two transmission lines offers the same problem as just outlined for the two transformer banks, *i.e.*, the main station switches should be equipped with inverse time limit relays and the substation switches with instantaneous differential balance relays.

The step-down transformers in the substation should also be

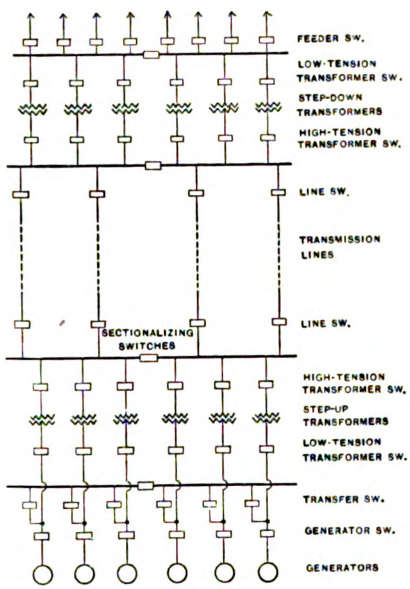


FIG. 3.

protected similarly to the transformers in the main station, and the feeder switches should be equipped with instantaneous overload relays, so as to cause an immediate disconnection of the feeder in which trouble occurs.

Fig. 3 is a diagram of a system of considerable magnitude. One transformer bank is provided for each generator and no low-tension bus is required; a transfer bus, however, being installed. What has been previously said about the protection of the generators applies in this case. Either non-automatic or automatic switches with definite time limit or reverse-current relays can be provided, while the transfer switches generally are made non-automatic.

Both the low-tension and high-tension transformer switches should be provided with inverse time limit relays or both switches can be operated from an inverse time limit relay installed on the side of the transformer which is opposite to the source of power; *i.e.*, the high tension side of the main station. This relay is then arranged to trip both switches and give selective action, as it is obvious that if a short circuit should occur in one bank the current through this relay would be practically the sum of the currents through the other relays, thus causing the relay in the fau'ty circuit to act quicker. The same applies also to the protection of the substation transformers.

Inverse time limit relays will evidently also give selective action for the transmission lines, when more than two are installed.

When the total generator capacity exceeds the rated rupturing capacity of the switchés, it has been common practise to provide one or more sectionalizing switches in the busbars. They are usually made automatic and provided with instantaneous overload relays, so as to confine any trouble to one section, and prevent the switches from rupturing more than their rated capacity.

An address delivered at the Annual Meeting of the American Institute of Electrical Engineers, New York, May 21, 1912.

THE DEBT WE OWE TO HENRY AS A SCIENTIST

BY MICHAEL I. PUPIN

The name of Joseph Henry is connected with the most brilliant epoch in the history of the science of electricity. To appreciate it fully, let us briefly describe the state of this science prior to the beginning of this glorious epoch—I refer now to the discoveries of the eighteenth century. Stephen Gray's discovery of electrical conduction in 1729 was the broadest foundation for subsequent work. Franklin's discoveries and philosophical speculations in the realm of electrical phenomena gave a tremendous impulse to further research. Galvani's fortunate discovery of the existence of electric force in the contact region of heterogenous bodies closes this period.

Substantial progress was made during the eighteenth century, but the progress was, comparatively speaking, slow and laborious. The intellectual atmosphere of the eighteenth century was rather heavy and quiescent, as if foreboding the approach of a mighty storm.

The storm arrived; the intellectual forces which, like a mountain torrent, broke loose during the French Revolution, and threatened to unhinge every human structure, receded rapidly to their natural channels. The torrent seemed to have washed away every impediment to rapid intellectual progress, and a vigorous advance was started in every direction of human thought. The triumphant forward march of the science of electricity begins now. Volta (1799) discovers the voltaic cell and teaches mankind how to generate electricity in motion. Oersted (1819) discovers the magnetic force exerted by electricity in motion, and Ampere a year later (1820) formulates the fundamental law connecting this magnetic force with the electrical

motion producing it. We have here three giants, Volta, Oersted and Ampere, accomplishing more in twenty years than had been accomplished before in the science of electricity in 2500 years. This kind of work and accomplishment reminds one of the forge of Cyclops as described in Homer's Odyssey. Every stroke shakes the earth to its very foundation. This was, indeed, a stupendous advance, yet it was only the beginning of the great period of electrical discovery and revelation, the period inaugurated by Joseph Henry and Michael Faraday.

Helmholtz and Thomson pointed out many years ago that Oersted's discovery is much broader than Oersted or even Ampere ever suspected, and that it embraces phenomena which these men never dreamt of, the phenomena of electromagnetic induction; or, to use a more descriptive expression, the phenomena of electric forces generated by the motion of magnetism. But to infer, from the existence of magnetic forces produced by moving electricity, the existence of electric forces produced by moving magnetism, it is necessary (as Helmholtz and Thomson point out), to have a clear vision of the principle of conservation of energy. This vision did not appear until nearly thirty years after Oersted and Ampere had finished their work in electromagnetism. But even if this great principle had arrived prior to the days of Oersted and Ampere, I doubt very much if the astuteness of any human brain would have ever gone so far as to infer, by pure logic, electromagnetic induction from electromagnetism. A logical deduction of this kind would stand today without a parallel in the history of human thought.

The fact that we can, today, in the light of the principle of conservation of energy, see a direct logical connection between electromagnetism and electromagnetic induction, is the best proof that the discoveries of Henry and Faraday furnish one of the most brilliant illustrations of the great power of the principle of conservation of energy.

But Henry's experimental work and Faraday's experimental work had to be done, and their great discoveries had to be made in the very manner in which they made them, in order to reveal before our wondering eyes the beautiful phenomena of electromagnetic induction. Nature guards her secrets too well to reveal a whole world of most startling phenomena to a man who makes no other effort than academic deduction by logic and pure reasoning. Our knowledge of physical phenomena advances by consecutive experimental steps; there

was no direct line from Oersted and Ampere to Henry and Faraday. We had to wait for Arago, who showed that electricity in motion magnetizes a steel needle, and we had to wait for Sturgeon, who showed that an electrical current circulating in a coil of wire wrapped around a horseshoe-shaped piece of steel made a magnet. This was the birth of the electromagnet in 1823. Henry was then a youth, 24 years of age, doing tutoring work in a private family in Albany, and in his leisure hours studying mathematics and reading such works as Lagrange's classical treatise on "Analytical Mechanics." He had never had, up to this time, an instrument for research in his hands, but in less than five years he became the foremost authority, and practically the only authority, on electromagnets. At that time, (this was prior to the discovery of electromagnetic induction) the science and the art of the electromagnet was undoubtedly the biggest problem in physics, and the very fact that Henry chose this subject for his study proves that he was cast for a great physicist. Willard Gibbs, our great mathematical physicist, said once that the most essential difference between a great and a commonplace scientist can be seen in the quality of problems which they select. A great physicist knows a great physical problem when he sees it. The electromagnet was a great problem, because it led to the discovery of electromagnetic induction; this was the key, and the only key, which opened the door of the secret chamber within which nature guarded the secrets of electromagnetic induction. Henry found the key and he opened the door which revealed to our wondering eyes the phenomena of electromagnetic induction. At about the same time, and using the same key which Henry had invented, the electromagnet, Faraday, independently of Henry, opened the same door. There can be no doubt as to Henry's claim. Sturgeon said: "Henry has been enabled to produce a magnetic force which totally eclipses every other in the annals of magnetism, and no parallel is to be found since the miraculous suspension of the celebrated oriental impostor in his iron coffin."

Henry worked day and night making electromagnets that could lift thousands of pounds, and these magnets are still in existence at Princeton and at Yale. If the master-mind which constructed these magnets had not discovered electromagnetic induction, and at the very time when the discovery was made, it would have been a miracle far more wonderful than the discovery itself.

Henry, it is true, never pressed his claim seriously. But he never pressed a claim; he never claimed anything; he was as modest as an angel and as unselfish as a saint. Besides, electromagnetic induction was so wonderful, destined, as he says, "to form a new era in the history of electricity and magnetism," that he would not permit himself in so big a thing as that to stand as a rival of the great Faraday.

It is thirty years to a day since I first saw Henry's discovery. I was a student at Columbia at that time, very fond of Greek and Latin, in fact so fond of it that I devoted most of my time to the study of Greek and Latin and classical literature. At the same time I was fond of mathematics and of physics, and of chemistry, and there was a doubt in my mind whether, when I graduated, I should take up as my life work classical studies or physics. One day I saw an experiment in the lecture room performed by the late Professor Rood of Columbia. He had a coil of wire, the terminals of which were connected to a galvanoscope, which was attached to the side of the wall so that the class could see the movement of the magnetic needle. The coil was in his left hand, and he had a magnet in his right hand. He moved the magnet a little bit, and off went the needle to one side, and then he moved the coil back, and the needle moved in the opposite direction. They say that magnetic needle moved because it is acted upon by the passage of electricity through the coil. Be that as it may, that needle, I am sure, was never as much thrilled as I was thrilled with that experiment, and I said, "good-by Latin, good-by Greek, I am going to study physics."

Imagine now how young Henry felt when he saw that magnetic needle thrill for the first time in the history of man when he moved the magnet in his modest laboratory at the high school in Albany. He himself tells what he thought of it, that it was destined to form a new era in the history of electricity and magnetism. You can see, then, why this man who was as modest as an angel and as unselfish as a saint could not thrust himself forward to dispute the discovery with a man as great as Faraday was at that time.

The same modesty and the same unselfishness which Henry displayed with regard to his claim as independent discoverer of electromagnetic induction, we find again in the case of his invention of the electromagnetic telegraph. Innumerable schemes had been proposed by various men, and at various times,

to transmit signals by electricity. Even the electromagnetic scheme was originated in many minds and at various dates subsequent to Oersted's discovery, but nobody understood the problem as well as Henry did, and nobody succeeded in solving it until he solved it in 1831.

Barlow was one of the originators, but the distinguished physicist admits his failure when he says, in 1825: "I found such a sensible diminution (of the magnetic force) with only two hundred feet of wire, as at once to convince me of the impracticability of the scheme."

Wheatstone, another originator of the electromagnetic telegraph scheme, says this, in 1837: "It would not act, and could not act as a telegraph, because sufficient attractive power could not be imparted to an electromagnet interposed in a long circuit."

Wheatstone was not aware, in 1837, that Henry had demonstrated the practicability of the scheme in 1831, and that he wound up the description of his experiments in the Silliman Journal, by saying: "The fact that the magnetic action of a current from a trough is at least not sensibly diminished by passing through a long wire, is directly applicable to Mr. Barlow's project of forming an electromagnetic telegraph."

The cause of Henry's success is due to his complete understanding of Ohm's law, discovered in 1827. Barlow did not understand it because it did not exist when he made his telegraphic experiments in 1824, and Wheatstone did not understand it in 1837, because the law was made in Germany, and Wheatstone was an Englishman. Henry had no international prejudices. Besides, Ohm's law was not the only thing involved in a complete understanding of the electromagnetic telegraph problem; the self-inductive reaction of the electromagnet, and of the long line, had to be adjusted, and Henry's rule was, to make the resistance of the line and the self-inductive reaction of the line small in comparison with the resistance and the self-inductive reaction of the electromagnets; in other words, use an intensity magnet and an intensity battery when working over a long line.

This is the alpha and the omega of the electromagnetic telegraph, and it belongs to Henry and nobody else.

If the principle is true that that man is the inventor who first constructs and describes an invention in such a way that anybody skilled in the art can practise it, then surely Henry is the real inventor of the electromagnetic telegraph.

But Henry with his boundless modesty calls it Mr. Barlow's project, and never lays any claim to it. Nay, he even recommends, in 1856, that an extension of Morse's patent be granted to Morse. Verily, verily, such men as Henry are not made of ordinary mortal clay.

You can understand now the motives which prompted me twenty-two years ago to back up with all my heart and all my soul the proposition first advanced by my honored colleague, Professor F. B. Crocker of Columbia University, that the unit of self-induction be named after Henry. The Congress of Chicago adopted this proposition, and it is a significant fact that the motion was made by an Englishman, Ayrton, seconded by a Frenchman, Mascart, and the presiding officer was a German, the great Helmholtz himself.

I shall now close my remarks by placing before you another picture which shows in even stronger light the remarkable qualities of this truly great man. In 1842 he described before the American Philosophical Society his wonderful discovery of electrical oscillations accompanying a Leyden jar discharge. He traces magnetic action of these oscillations at a distance of thirty feet, transmitted there through walls and floors of a house. The detector is a steel needle which is magnetized by the transmitted oscillations. In this lecture Henry says: "The author is disposed to adopt the hypothesis of an electrical plenum, and from the foregoing experiments it would appear that the transfer of a single spark is sufficient to disturb perceptibly the electricity of space throughout at least a cube of 400,000 cubic feet of capacity; and when it is considered that the magnetism of the needle is the result of the difference of two actions, it may be further inferred that the diffusion of motion in this case is almost comparable with that of a spark from a flint and steel in the case of light."

Who does not feel in reading these lines that Henry knew instinctively that he was facing here a problem containing boundless possibilities? I am sure that he saw before him wireless telegraphy and the electromagnetic theory of light. There was no topic that he loved to discuss with his friends as much as the oscillating discharge of a Leyden jar. I can imagine how a man of his years (he was only 43 years of age at that time), and of his accomplishments, must have been eager to throw himself heart and soul into the study of this great and most fascinating problem which he had formulated himself. But, alas, his

country calls him to other duties, and he bids good-bye to the academic groves of Princeton where he had spent so many happy hours in scientific study, contemplation and discourse with nature. He went to Washington to serve his country in organizing the Smithsonian Institution, and he knew that this meant adieu to Science for many years to come, and a bitter fight with crafty lawyers and cunning politicians who are eager to get hold of the Smithsonian Foundation, and fight about the definition of what Smithson meant when he said its foundation was for the purpose of advancing science and diffusing knowledge. The lawyers maintained that Smithson meant the building of libraries and filling them with law books, and the politicians said that Smithson wanted to buy seeds and send them to farmers, through the medium of the Representatives, so as to get new votes for Congressmen and Senators.

Now, what Henry did, you can easily guess, and what he thought you can easily guess. There was a struggle in which Henry engaged with his whole heart and soul for a number of years, and he conquered because on the one side there was the craftiness of the lawyer and the cunning of the politician, but on the other side there was justice and Joseph Henry. The Smithsonian Institution was then organized in accordance with these ideals, and we have today a splendid research laboratory, and we have a splendid museum. From the Smithsonian Institution nurtured by Joseph Henry sprang the magnificent scientific bureaus in Washington which are doing such splendid work. We have the National Academy of Science, and above all things we have a scientific spirit in Washington, the background of which is the spirit of Joseph Henry.

Joseph Henry loved his science, he loved his work, he loved his fellow man, and above all things he loved his country, and the duty he owed his country.

And now, Mr. Torchio*, the American Institute of Electrical Engineers could think of no better symbol to present to your Society than the bust of Joseph Henry. The American Institute of Electrical Engineers is aware that the Italian nation has great men, whom the Italians delight in honoring, and we know that in your Hall of Fame there is no man who can occupy a place with so much dignity as Joseph Henry. He is one of the

*Mr. Philip Torchio, special representative of the Associazione Elettrotecnica Italiana.

very few men who can stand side by side and share companionship in your Hall of Fame with men like Galileo, Galvani, Volta and your Marconi of the present day, and with the bust of Joseph Henry, our Institute extends to your society its warmest greetings and its kindest regards.

A paper presented at the Toronto Section Meeting of the American Institute of Electrical Engineers Toronto, Can., February 2, 1912.

ELECTRICITY IN THE PORTLAND CEMENT INDUSTRY

BY F. C. E. BURNETT

There are probably many persons who can recall the time when Portland cement was considered to be a luxury in building all but the finest and greatest structures, owing to its high cost, and to a certain extent, to the uncertainty of the quality of the product. During the last twelve years those connected with the industry have been working hard on improvements in the methods of manufacture, and the improvement in quality and reduction in price speedily led to a great increase in the consumption of cement. These improvements were rendered possible by the introduction of the rotary kiln, and also by improvements in the grinding of refractory materials, which have had a much more serious study during that period than at any time previously; improvements in conveying machinery have also had not a little to do with the economical manufacture of Portland cement.

The introduction of reinforced concrete construction as a basis of a modern building has resulted in an enormous increase in the consumption of Portland cement in recent years, apart altogether from the increase due to its being used to a greater extent on an entirely different class of work, where it replaced stone or brick. It has also become the leading factor in the construction of large public works, such as docks, where the huge blocks of stone have been largely replaced by similar blocks of concrete. Some idea may be gathered of the increase in consumption, when I state, on the authority of a recent U. S. Government report, that the quantity used during the year 1910 was nearly ten times as large as that used during the year 1900. It has also given birth to a

number of other industries for the manufacture of cement products such as drain pipes, bricks and artificial stone, paving materials, and certain classes of refractory materials that now use a certain proportion of cement in their manufacture. It can safely be said that the recent developments in the manufacture of cement have made this great increase in consumption possible, by creating a demand hitherto unthought of, the reason being that the manufacture of Portland cement has shown the way, and has kept ahead of the demands made upon this product. As an instance of this, the improvement in the quality has come from inside the trade and not from external pressure, and the engineer's specifications have followed up in the rear.

Owing to the fact that the development of the industry has come from the inside, and has been in the hands of the most capable members of the engineering fraternity, it happens that the employment of the electric motor in the process of manufacture has now become a matter of history, and, doubtless, the needs of the industry have contributed in some small measure to the development of the electric motor along certain lines. The modern cement mill is now designed and built as a matter of course for electric driving, as the operation of the mill is a much simpler matter when this system is employed, and there are many features in the design of the mill which are greatly simplified by its adoption, the discussion of which, however, is outside the scope of this paper.

The Portland cement industry ranks among those of the heavier class, where the power consumption forms a quite considerable proportion of the manufacturing cost, a condition not often met with in any other manufacturing process. It does not employ such a large amount of power as, say, the steel rolling mill, nor are the units as large, rarely exceeding 200 h.p. in size, where individual driving is adopted. There are, however, problems which are peculiarly its own, and these will be dealt with as we proceed. To those who are not already familiar with the manufacturing of what is now known as Portland cement a brief description here will not be out of place.

Portland cement is the powdered slag resulting from the fusion of limestone and clay, which has the right mixture of alumina and silica. The lime may be in the form of rock or marl; when in this latter condition, the process is known as the wet process, the former being the dry process, most common on this continent at the present time. The limestone is chosen as pure as possible,

and it must have a greater proportion of iron than a certain amount, otherwise a cement of dark and uncertain color will result. A proportion of iron is useful, forming a flux which assists in the fusion of the materials in the kiln. The site for the mill is chosen where the correct limestone and clay can be readily obtained, as it is of prime importance that the costs of quarring these materials and getting them to the mill be kept as low as possible, because any double handling, which would be necessary were a long haul of any of these materials to take place, adds enormously to the cost of production.

The limestone is quarried in the usual manner, and brought to a crushing plant, where it is broken into suitable fragments, and then passed through a dryer, to get rid of the moisture which is always present, and which hinders grinding, in the dry process. The clay is similarly dried, and the two are mixed in the proper proportion, and ground together to insure an intimate mixture and a product of uniform quality. The mixture is then fed to the kilns, where it is fused to a clinker, quenched with water, and then generally thrown on to the clinker pile to cool. It is then passed to the clinker grinding department, where a small proportion of gypsum is added to control the setting, which would otherwise be too quick for ordinary practical working. In the clinker grinding department, it is ground to the requisite degree of fineness, and is then ready for use as cement, after it has cooled to atmospheric temperature.

Simple as this manufacturing process seems, and really is, it involves some large problems, the principal one being that of grinding, as all who have had anything to do with the grinding or refractory materials are well aware.

One of the illustrations shows a typical quarry where the limestone is obtained; the rock is worked in benches of convenient depth, after the overlaying layers of clay and loam have been stripped off. The rock has to be broken in the quarry to a size small enough to pass through the crusher, and hence the method of blasting has to be carefully considered, and the proper powder for that particular formation of rock has to be chosen with this end in view. In this particular quarry, the rock is picked up by a steam shovel, which fills the quarry cars of about ten tons capacity, these being then hauled to an electric hoist and tipped to discharge their contents into the crusher cone. There are generally two sizes of crushers employed, one, of large tonnage capacity, which handles the whole of the rock, from which it

passes to a second set of crushers, which break it up into a size convenient for drying and for grinding.

The method of obtaining the clay will depend upon the amount that is required to give the correct mixture to produce cement. The rock may vary from a true cement rock, which already has the proper amount of clay naturally mixed in, in the process of formation, to a perfectly pure limestone rock, which contains no clay whatever. If only a small amount of clay is necessary, it may be obtained by manual labor, and carted, but when required in large amounts, it is generally picked up by a steam shovel, which tips it into cars to be hauled to the clay dryer.

The crushed stone is generally stored, to insure a regular supply to the mill, as the quarry has to be worked intermittently on account of the necessity for blasting, and, of course, the process of manufacture must go on continuously.

Limestone, of course, in its natural state, contains a considerable amount of moisture, which has to be dried out before it can be economically ground, and the stone is therefore taken from the storage and passed through driers. These driers consist of revolving horizontal cylinders, on a slightly inclined axis, along which the stone rolls by gravity to the firing end, and hence to the conveyers. The drier is fired either by the waste gases from the kilns, or separately, from the discharged end, induced draft being generally employed. The clay has to be similarly dried, the drier being of the same size and type, and both stone and clay in their passage through the driers are further slightly broken up, thus assisting the final grinding of the raw material. The dried stone and clay are then allowed to cool before being passed to the raw grinding department.

There are many types of grinders emloyed in the pulverizing of both the new raw and the burned product, but probably the most commonly used and the best known are the ball and the tube mills. The former consists of a short cylinder, of large diameter, partially filled with steel balls, which, as the cylinder is revolved, roll on the material to be ground and hammer it to a certain degree of fineness. The ball mill is used to give the preliminary grind to the clay and stone, which are ground separately in this stage. The clay and stone are then mixed in their proper proportions, depending on the composition of the limestone, and are then fed to the tube mills, which complete the grinding to the requisite degree of fineness for burning to clinker. The tube mill consists of a large tube, anywhere from five to seven

feet in diameter, and from 18 to 22 feet long, revolving on a horizontal axis, and lined with a refractory material, and partly filled with flint pebbles. The raw mixture is fed into and passes through the mill by gravity, being thoroughly ground in its passage till from 92 to 94 per cent passes through a sieve having 100 meshes to the inch. This raw grinding is of quite as great importance as the grinding of the clinker, as an imperfectly ground raw mixture will not clinker properly, and will give a poor quality of cement. This thorough grinding is necessary to insure the intimate mixture of the materials, in addition to helping fusion.

The raw mixture is then fed to the rotary kilns, where it is burned to a clinker. The rotary kiln is a long tube lined with firebrick, revolving on an inclined axis, and fired with coal in a pulverized state, which is blown into the kiln with fans or compressed air, giving a burning temperature at the hottest part of about 2900 deg. fahr. As in the drier, the raw material simply passes through the kiln by gravity, the rate of flow depending on the speed of the kiln, which is variable, and may be controlled either by mechanical means, or by variable speed motors. As the burned clinker leaves the kiln, it is quenched to kill any uncombined lime that may be present, and then put into storage to cool. It may be passed through a cooler on its way to storage, if intended for immediate use.

After cooling sufficiently, the required amount of gypsum is added to the clinker, then the mixture is forwarded to the clinker grinding department, there to be ground in a manner similar to that in the raw grinding department, when the material is ready for use after cooling to atmospheric temperature.

It is usually stored in convenient bins, from which it is drawn to conveyers, and either packed by hand, or fed to bagging machines, to be put in the familiar cotton sacks, or occasionally in wooden barrels.

From the above brief description, it will be seen that the manufacture of Portland cement lends itself admirably to the adoption of electricity for motive power, either as an individual drive, or in very effective arrangements of group driving, though, where power is cheap, as we have it here in Canada this latter arrangement is not very much in vogue.

Before going further into the discussion of the various drives, it might not be out of place to take up here some of the primary questions in connection with the electrical equipment. First

and foremost comes the choice of the system, dependent on the type of motor adopted. The simplicity of the induction motor of the squirrel cage type commends it to all practical mill men; it has little to get out of order but the bearings, and, as reliability of operation is of prime importance, the process being a continuous one, this is the type of motor most generally adopted in all modern cement mills. This brings us at once to the choice of the alternating-current three-phase system. There are some who pin their faith to the direct-current equipment, but the writer has had no experience with this system in a cement mill, except to a very limited extent, and hence cannot give any suggestions on its operation. The direct-current motor can be of great use about a mill where its variable speed characteristics can be employed, but there is little of this work about the cement mill, the larger part of the equipment being run at constant speed, and hence there is no apparent necessity for the adoption of the direct-current system in its entirety in this industry. It has the great disadvantage of being much higher in first cost than the alternating-current system, and the complication of the starting equipment means high maintenance costs.

There are other motors besides the squirrel cage motor that have their uses in the cement mill, and the slip ring type of motor is indispensable for hoisting and similar work. This motor has also its advocates for general mill use, on account of its high starting torque, and, where a separate motor house is provided for this type, I think that this motor will be found to give excellent results, especially in plants having their own power house, where regulation becomes a matter of importance; its use will avoid clutches, with their excessive repair costs, on the one hand, and excessive motor capacity to gain large starting torque on the other hand. Against this must be placed the extra amount of attention necessary in order to keep this type of motor in service continuously, as it is necessary to keep in mind the fact that the whole equipment is working for 24 hours a day, and 365 days a year, and a load factor of about 75 to 80 per cent is expected on the whole electrical equipment, over the year's operation.

Yet another type is the internal resistance motor, which has been used for this work, but the writer does not recommend this type, not on account of any inherent defects in the motor itself, but from the fact that it takes a fairly intelligent staff to use it properly, and, as a rule, the labor employed in the cement industry does not come under this category. If the contact

brushes are not returned to the end of the rheostat every time the motor is shut down, there is slight burning at the contact surface due to excessive current, and this speedily causes trouble which entails the renewal of the resistance elements,—a costly job. Then, as happens on occasion, if the motor is thrown on the line with the brushes in the running position, the brushes are then burned off entirely. Beyond this, the motor is very useful within its sphere, and is similar to the slip-ring type in characteristics. The great advantage of these two last types is their high starting torque with small line current, a point not to be lost sight of, and having a considerable bearing on the cost of the electrical equipment maintenance. High torque is essential for starting up ball and tube mills, and, to gain this with the squirrel cage type means the installation of a larger motor than is necessary for normal running. Against this, however, is to be set the more expensive equipment with the slip-ring type, and also, the same fault is found in the slip-ring type as in the internal resistance type, namely, the destruction of the brushes should the motor be thrown on the line with all resistance out. In the first cost, however, a considerable saving may be effected by the adoption of the liquid starting rheostat, which has not found much favor in this country yet. We have some of these at one of our mills, of a home-made pattern, which were temporarily installed, and which answer their purpose excellently until such time as present construction work is through, when time can be given to making them permanent. The slip-rings are also of home design, with their short circuiting device, but unfortunately a view of them cannot be given. The short-circuiting brushes are of phosphor bronze, attached to a sliding sleeve, which can be removed with the brushes by taking off the end shield; putting in a new set is only a matter of 30 minutes.

There are, however, other disadvantages in this type of motor for cement mill work. The conditions inside the mill are far from ideal as regards cleanliness of atmosphere; the dust from the grinding will get about in a marvellous way, in spite of all efforts to avoid it, and this dust collects moisture very rapidly, and is liable to cause trouble in the rotor windings, from which it is not easily cleaned. The stator is comparatively easily cleaned, and provision is made with a supply of air under pressure near each motor for regularly blowing the dust out. The rotor, however, owing to its construction, is not so easily cleaned, and it must be remembered that the voltage between phases on

the rotary may be very high on first throwing on the current, and the insulation has naturally to be somewhat skimped if excessive rotor dimensions are to be avoided. Trouble is experienced in these windings due probably to the moisture in the dust. Then there is the wear and tear on the slip-rings and brushes of the slip-ring type, due to the clinker dust and the cement, and, strange to say, about the worst of all, the clay dust. If, however, these motors are housed separately from the machines they are to drive, and well looked after, they should make a very successful drive.

It will be seen from the foregoing that the squirrel cage type easily holds the field for general work in the cement mill, and it is really wonderful the amount of abuse it will stand in the course of its life; even if mistakes are made in switching—a most common occurrence—nothing very serious will happen, beyond blowing the fuses. I might here mention that these switchings mistakes will happen even in the best of well regulated mills. As is well known, the usual starter for the squirrel cage motor is provided with a supposedly fool-proof handle, to prevent a man going on to the running side first. It occasionally happens that a man in a hurry, will lift the catch and put the motor on the line direct before he quite realizes what he is doing, but the only thing it is bad for is the fuses. Apart from this, there is really very little trouble with this type of motor from an operating point of view. Of course, it has a very poor starting torque, and this has to be got over by installing a motor of slightly larger capacity than is necessary to operate the machine to which it is coupled; the losses in efficiency from full to three-quarter load are not as a rule very serious, if present at all, and the power factor is not very seriously less than a full load, if the motor is well designed. It is now the practise among some to use a booster transformer at starting to obtain the necessary starting torque, but this is rather a heroic method; it is claimed that it will not harm the motor, a statement which the writer very much doubts, while the wear and tear in the starting gear must be greatly increased. There are other considerations also, such as the stresses set up in the belts and gears. When excessive voltage is applied at the start, the torque of the motor before it reaches synchronism may reach seven or eight times the full load torque, and the consequent acceleration at this point is very high indeed. Now, the cost of maintaining belts and gears in large plants of this type is very high, and too high a torque reduces the life very

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FIG. 1.—TYPICAL QUARRY. STEAM SHOVEL ON ROCK ON LOWER LEVEL. STEAM SHOVEL STRIPPING CLAY ON UPPER LEVEL.

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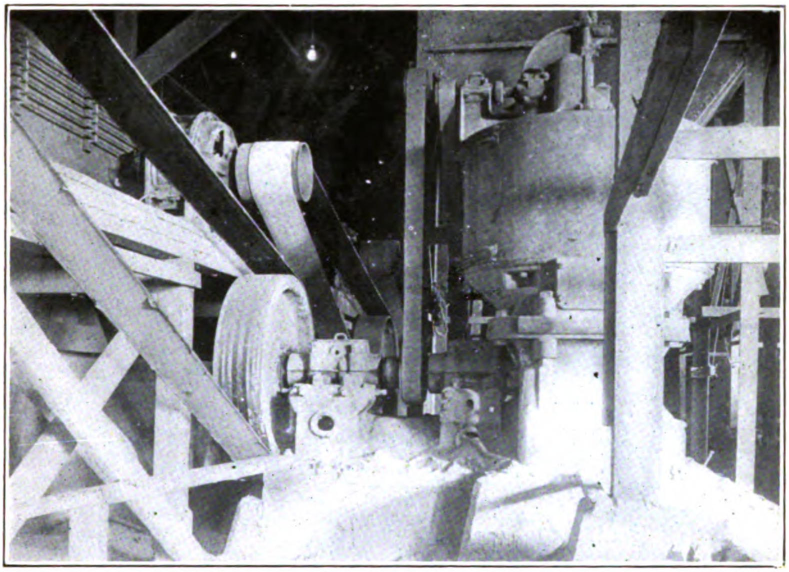
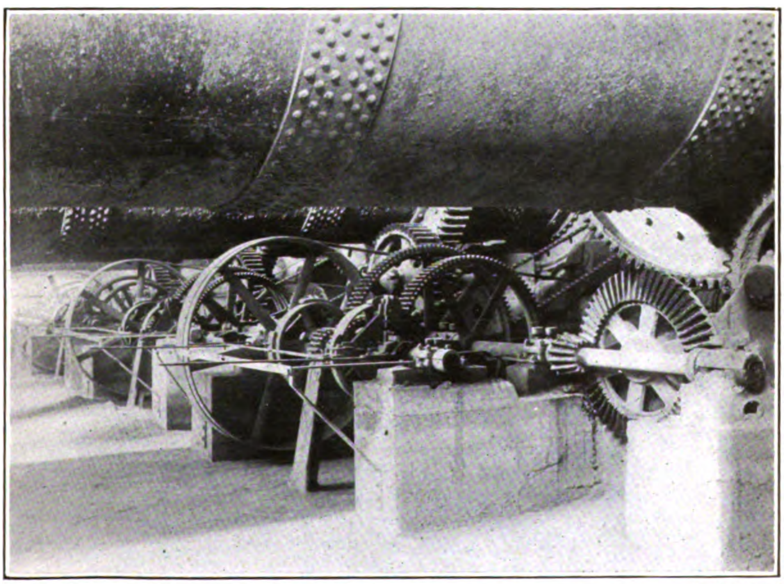
FIG. 2.—ELECTRICALLY OPERATED TWIN HOIST, CAPACITY 10 TONS OF ROCK PER LIFT.



[BURNETT]

Fig. 3.—75 h.p. Motor Drives for Pulverizers on Raw Material.



[BURNETT]

Fig. 4.—Driving Gear for 9-ft. 6-in. by 150-ft. Rotary Kiln. Motors Belted to Large Pulleys.

quickly. The motor to which they are coupled will give its maximum torque when it is accelerating, and the greater portion of this is transmitted to the belts and gears. This load in its effect on the fibers of the leather or gears is independent of any time element, but is strictly a static stress, so that heavier belts are necessary where such conditions prevail than when starting conditions are normal.

The above remarks apply primarily to the individual method of driving, which is the favorite one from an operating point of view. In changing from steam to electric driving, it may be advantageous to retain the group method, which will be found to be about the best group that could be chosen in any case. It has advantages to recommend it, chief among which is economy in power consumption, lower cost of belt maintenance, more economical type of motor, lower maintenance charges, and lower investment for equipment in the first place. Then the conditions for the motor are better, as this type of drive is generally separately housed. Against these are to be set the lack of flexibility requiring the shutting down of a large part of the mill for one machine, and the necessity for friction clutches throughout for all drives, which are a source of trouble and expense. In spite of the clutches, there is a considerable amount of shutting down necessary, say to put on belts or chains, or to repair the clutches themselves. If the latter are put in large enough in the first case, however, they can be run to give little trouble. A good combination can be made up of group and individual drives, grouping all the heavy machines, and using small motors for the lesser drives, such as conveyers and elevators, etc. One of our mills uses this latter type of driving, where slow speed engines of the horizontal corliss type were replaced by induction motors in the raw and clinker grinding departments, and to which we will return later.

The choice of frequency is not of very great importance. Anything between 25 and 63 cycles is suitable, and does not lead to any trouble in adapting the pulleys with a reasonable motor speed. If a choice of frequency can be made, then the 25 cycle system is best, as then slow-speed motors can be obtained without the consequent sacrifice in power factor. There is also less differences in pulley sizes, which lends to long belt life,—a very important factor. Against this is to be placed higher first cost and weight. The sixty cycle motor has proved itself to be quite equal to the occasion, and where belts are liberally

chosen, and proper counter shaft speeds adopted, there should be little trouble from this cause. It might here be mentioned that the greater portion of the machinery is very slow speed, and hence intermediate shafting of some sort is generally necessary. In some cases direct drives have been adopted for the grinding mills, but, in the writer's opinion, it is much too rigid an arrangement for this class of work, where the units do not exceed 200 h.p. in size. It may be satisfactory in larger sizes.

Of greater importance is the choice of voltage. At first sight, it would seem that the 2200-volt system would be the best owing to the large amount of power to be handled, and the saving in copper to be effected by its adoption. There are many other things to be considered, however, and first of them is safety in operation. With group driving, the 2200 volt system can be installed to great advantage with perfect safety, but such is not the case with individual driving. The motors become so scattered, and the wiring so disturbed that, while it can no doubt be made quite safe in the first case, the necessary amount of safety costs too much to make it worth while. I might here say that my short experience leads me to abandon any form of conduit work about the mill where it can be avoided. It is not possible to keep the dust out of the conduits, and this dust gives constant trouble. The only way to avoid it is to fill up the ducts with compound, which reduces the flexibility of the system, whose keynote is constant change at the present time. While the larger individual drives could well be arranged for 2200 volts, it must be borne in mind that all the conveying and elevating gear, and fans, and similar small drives, require small power units, and these are the very drives that cannot be grouped with anything like convenience in operation, and these must be supplied with power at 550 volts as a maximum, The size of motor for such drives varies from 10 to 50 h.p., and they cannot be economically wound for anything higher than 550 volts. We are therefore under compulsion to adopt the lower voltage for the smaller motors, and it does not seem reasonable to have two different voltages. Then, conditions about a cement mill are such that the insulation of a 2200-volt motor must be specially good, as the cement and clay dust take up a large amount of moisture in damp weather. The writer has seen motors in wet weather through which a bank of lamps could be lit, but when they were cleaned and dried out, the insulation was found to be in perfectly good shape. Taking all things into consideration, the writer is

of the opinion that the 550-volt system is the most satisfactory all round. It enables a very efficient motor, with a high power factor to be used and these are characteristics which are very desirable when power is purchased. Then, should workmen come in contact with any live wires, the results are not fatal; no case of a fatal shock from this voltage has yet come under the writer's notice. As a rule, the only effect of such shock is to make the men much more careful in handling the electrical equipment—a most desirable result.

The wiring is better carried out on the open principle, with everything in full view, this system being carried right up to the motor wherever possible. In this way, faults in the cables are practically eliminated, and, when they do occur, they are easily localized and quickly remedied. For convenience in handling, the various departments are divided up by feeders, which are generally arranged to be about the same capacity, to ensure uniformity in switches and gear, reducing the number of spare parts to be carried in stock at one time, and enabling one to carry a more satisfactory stock of parts for less money. The system the writer recommends is that of running the feeder in the most convenient location along the department to be served, and branching down to each motor panel. The feeder is protected in the power station, or the substation, and each motor is also protected by its own cutouts. A system of simple motor panels appears to be the best, the panel being made up of wood framework, on which are mounted the motor control switches. Using the above arrangement of feeders for each department, each motor must be capable of entire disconnection from the line, to effect repairs to the oil switches, or to the starting compensator without making the whole feeder dead. It will therefore be found advisable to have a plain knife switch at the top of the panel, out of reach for all ordinary operation, and which is only intended to be used to make the circuit dead when working on the motor or the switch gear.

The fuses should be three in number, one of which may be heavier than the other two. As the majority of compensators are now fitted with no-voltage attachments, the taps for this are taken from the two lighter fuses, so that, in the event of the fuse blowing, the release is dropped, thus cutting out the motor. The use of these no-voltage releases is imperative in this class of work, where the power is liable to be suddenly shut off, as they will save their own cost in a short time in saving fuses. Every time

the power is shut off, no matter how much care is taken in instructing the men, there will always be some motors left in the running position, with disastrous results to the fuses when the power is again switched on.

Many makers now make overload relays for use with the no-load releases, and the writer has tried them out in this work with very good results. They are enclosed, to protect them from the dust, and, though it was feared they would be unsatisfactory in operation, due to the dust, they have proved themselves to be quite reliable. They are cheaper in first cost than oil switches, and probably much more reliable and should have a very low maintenance charge, which places them a long way ahead of fuses.

In addition to this apparatus, it is advisable to have a light, or cluster of lights on each motor panel, connected on the running side of the leads, and it will then show from a distance whether the motor is in operation or not. This is especially necessary on motors driving conveyers or elevators; these are very important drives, though small, and one of these out of commission for a few minutes usually results in whole department being shut down for some time in order to dig out choked conveyers or elevators.

Little can be said of a very definite nature about the size of motors required for the different classes of machines, as they all vary in size to such an extent, that all depends on the machine installed. Definite information can be obtained from the makers of each type, for the size of motor best adapted for the particular mill under consideration. This information is now fairly reliable, though care must be taken when makers are trying to sell machines on the basis of low power consumption, when a certain amount of incredulity must be exercised over the exact size of motor, and one of slightly larger capacity adopted than the one recommended. Small crushers take little power, and are generally grouped to drive from one motor. The larger crusher should have its own individual drive, and the motor should be of ample size; it is quite safe to take the maker's rating for such machines, as they fully recognize the unwisdom of putting in too small a motor for such a drive, and the trouble entailed if the motor switch is tripped through overload. Driers are a light drive, and the usual setting for this department is a modified group drive. Each drier is treated as a unit, with its fan, feed screw, and rotating mechanism; depending on the size of drier chosen,

the motor will vary in size from 30 to 75 h.p. There is little difference between the amount of power required to turn the drier empty or full, the power being required simply to overcome friction, the load in the drier having little effect.

In the grinding machinery, there is also a great divergence in the size of the motor required, depending on the type of grinding adopted. Many mills have a comparatively low power consumption, but a high maintenance, while others have a high power consumption and low maintenance, and the choice of mill will therefore depend on the power cost. The most commonly employed belonging to the latter class. Depending on the size, a ball mill will require a motor of from 50 to 100 h.p. and a tube mill of from 75 to 175 h.p. There is no gain in efficiency in adopting a larger type of mill, the increase in output being just about proportional to the increase in size, the only advantage being in the larger unit, and the saving in space resulting. The data on the correct size of motor to be used for any particular size of mill of the above types is now accurate and complete, and can be followed without modification.

The motors required for the kilns are comparatively small. The modern kiln varies in size from about 6 ft. 6 in. by 100 ft. to 10 ft. 6 in. by 200 ft. The speed of rotation is so slow, and the balance is so good, that the actual power required is small. To take a typical case, the size of motor installed for a kiln of 7 ft. 6 in. by 150 ft. with its feeding apparatus, is 25 h.p. The actual power required to keep the kiln going is about half the motor rating, but the size is chosen on account of the high temperature in the neighborhood of the kiln, to avoid overheating of the motor. This motor is placed on the same floor level as the kilns, but some kiln rooms are designed for a motor floor beneath the level of the kiln room, the belt coming up through the floor to the main pulley of the kiln countershaft and change-speed gear.

It is desirable to have an adjustable speed drive for the kilns, and in some cases direct-current motors are installed for this purpose, with shunt field control. This makes a very handy drive, and is much preferred by the burners, who can control their kilns from the firing front. As a general rule, however, a two-speed gear is employed, which has been found to answer the purpose admirably.

The amount of power in all required for the auxiliary machinery is small, and rarely indeed amounts to 10 per cent of the requirements of the various mills. Elevators and conveyers take little

power, but it is the usual practise to use nothing less than a 10 h.p. motor on a 550-volt system, as considerable trouble is experienced through breakdown of the windings on smaller motors at this voltage. Belt conveyers take little power, and screw conveyers, when once filled, float on the material to be conveyed and hence have little bearing friction. Little information can be given here that would be of any service, so much depends on the layout of the mill; and the total amount of power for this service, as mentioned above, is unimportant, and would not warrant the amount of space that would be necessary to give anything like a complete list of the power requirements of the different types of conveying and elevating machinery on the market.

There are other requirements about a cement mill which will depend on local conditions. The supply of compressed air for the quarry rock drills, and for cleaning motors, must also be considered in taking into account the total amount of power required for the complete mill. There is also a water service to provide for, and an emergency service for fire purposes. The machine shop, smith's and carpenter's shops also require their motors, and other small power units will be used for a variety of purposes, according to the views of the designer and the owners.

Where group driving is adopted for the grinding mills, a smaller allowance of power is allowable, as, when once the motor is running, the extra torque necessary to start up one mill from rest is not a large proportion of the total torque at full load, if more than three of the mills of the same type are driven by one motor. It is necessary to have a friction clutch for each mill, in order that any single one may be taken out of commission for repairs, and the cut-outs can be so adjusted that the extra current will not bring them into operation.

There are many mills on the market which do not require an excessive torque at starting, and hence these remarks do not apply to these mills, and, in others again, the torque increases with the speed, a condition which admirably suits the squirrel-cage motor. With either of these classes, it is quite practicable to start up the motor with all clutches in, should a group be shut down for any reason. The same thing can also be done with the heavy-torque, slow-speed mills, if a slip-ring type of motor is adopted, and hence, in this way much wear and tear clutches and belts is saved, as a reasonable time, under the control of the operator, can be taken to start up the group. Such cases, as a rule, will only be met with on changing from steam engine drive

to electric motor drive, one such case having come under the writer's consideration.

In this case, two 1200-i.h.p. steam engines were replaced in by four 600-h.p. squirrel-cage induction motors, two being employed in the raw grinding department, and two in the clinker grinding. The main shaft in the raw grinding mill was uncoupled at the center of the load, and a motor belted to each section of the shaft. The countershafts for the various conveyers and elevators were driven by individual motors. One large motor had three ball mills and three tube mills, and the other had two ball mills and three tubes, this carrying a somewhat lighter load. In the clinker mill, the engine had formerly driven two shafts, each equally loaded, and a motor was belted to each of these, with the auxiliaries separately driven by small motors. Here each motor was loaded with eight Griffin mills and three tube mills. Clutches were used throughout, and the motors and line shafts started up with all clutches free; it was thus possible to employ squirrel-cage motors with a high power factor and efficiency, the motors on test giving, by the Steinmetz method, an efficiency at full load of 95 per cent and a power factor of 94.5 per cent. They carried continuously a load varying between 75 per cent and 110 per cent of full load.

Before the installation of the smaller motors, the large motors drove the conveyers and elevators, just as has been done with the steam drivers. This meant a shut down at times of three or four times a day to repair chains on the small drives. The longest continuous run under these conditions was 80 hours, while after the installation of the small motors, shut downs of the large motors were very infrequent, one run of 200 hours having been recorded to date, and there is no reason why this cannot be exceeded. When a conveyer or elevator drive now breaks, the small motor only is shut down, the clutches on the mills being thrown out if necessary, pending the required repairs of the auxiliary, which rarely occupy more than a few minutes, except when the conveyer or elevator itself is actually broken. In this way, much valuable operating time is saved by keeping the main shaft in motion all the time, only shutting down when necessary to effect major repairs to the main running gear.

The total power taken by the mill will vary greatly, and, as already mentioned, will depend primarily on the type of grinding machinery adopted, and, after that, on the layout of the mill and the common sense of the superintendent. The power

consumption is on the basis of one band per 24 hours, and care must be exercised in stating, or ascertaining whether the figure given is the maximum or average power.

In installing generating plant, the capacity of the generators or prime movers must be chosen with due regard to the maximum load intended to be carried, and due regard must be paid to the probable duration of the maximum, or peak load. A peak of five to 15 minutes duration, with intervals of lower load for longer periods, may safely be carried, where a 20 minute peak might encroach dangerously on the overload capacity on a basis of say, a 15 minute peak load. On this basis, the actual power required for a mill of, say, 3000 barrels per day nominal capacity, may vary from 1.1 h.p. to 1.5 h.p., depending on the equipment and design.

Another method is that of basing the power on the average load, or the number of horse power-hours per day divided by 24. This is usually the notation adopted when one is selling grinding machinery, if the power problem is being closely investigated. On this basis, the average horse power per barrel per day will vary from about 0.7 to 1.1.

The scientific basis, is, of course, a combination of the two, the capital charges being based on the peak loads, and the energy consumption on the horse power-hour basis.

Power in bulk is usually sold in this way, being contracted for on a price per kilowatt or horse power of peak load, (or maximum demand, as it is generally known), and a second price per kilowatt-hour, or horse power-hour, which will vary with the load factor, or ratio of average to peak load, or may be fixed at a definite unit price at a given load factor—usually 80 per cent with a 24-hour service. Hence the necessity of looking at the power problem, and also the need for close investigation of the claims made for power consumption for any mill, from both aspects is apparent, before entering into any contract for power supply, and expert advice should always be sought from an independent and disinterested source on this matter.

Let us turn to some considerations regarding the operation of the electrical equipment. Anyone operating a cement or similar mill, must bear in mind the fact that trouble is, in the nature of things, bound to crop up in great measure in all departments, not forgetting the electrical. The service is very severe. In other trades, it too often happens that the poor electric motor, which may have replaced a steam plant, employing many men, is supposed to run without any attention whatever, as the writer

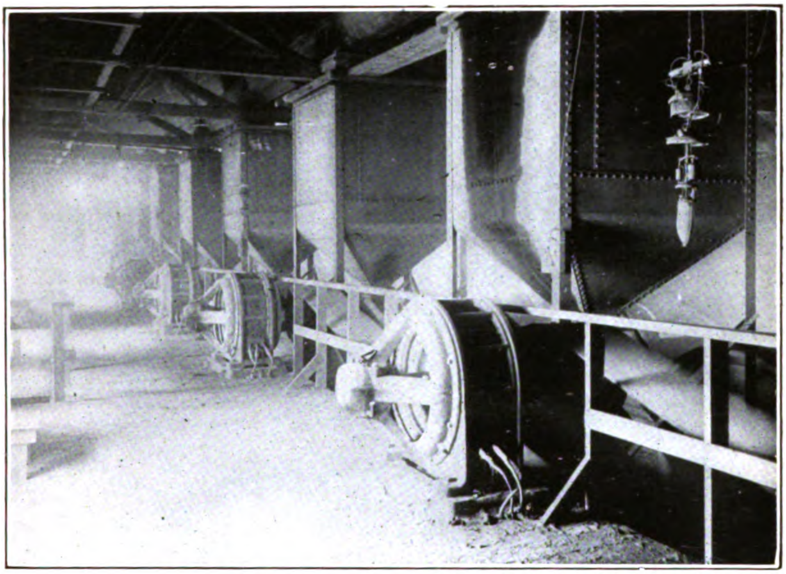


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FIG. 5.—PART OF BANK OF 150-H.P. MOTORS DRIVING TUBE MILLS.

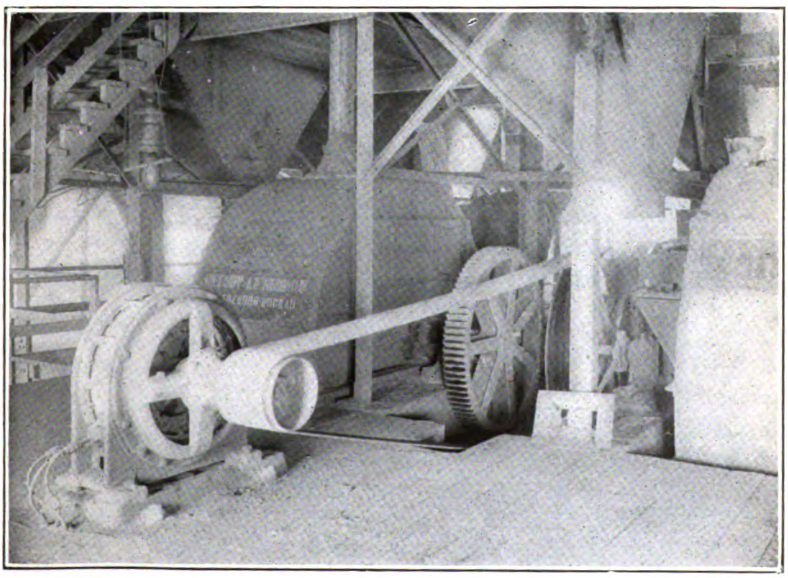

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FIG. 6.—75 H. P. MOTOR DRIVING BALL MILL ON CLINKER.

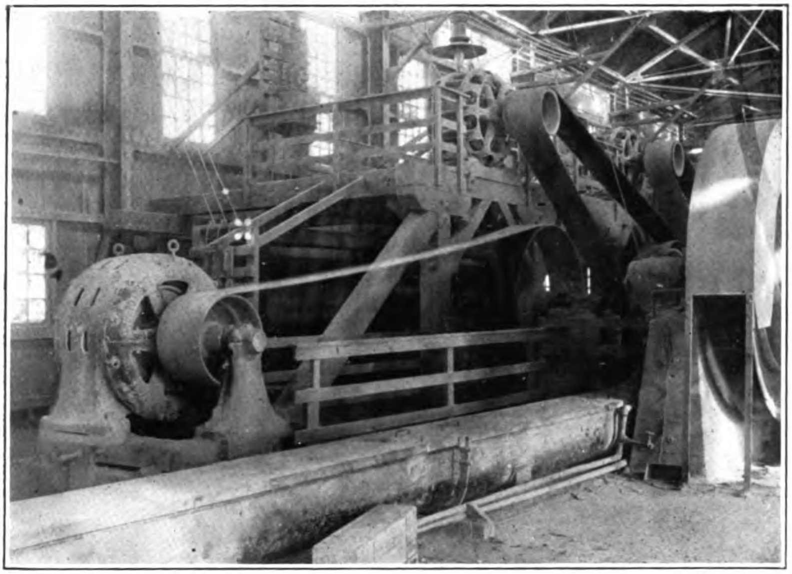

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FIG. 7.—EXAMPLE OF MOTOR GROUPING FOR DRIVING TUBE MILLS GRINDING CLINKER.

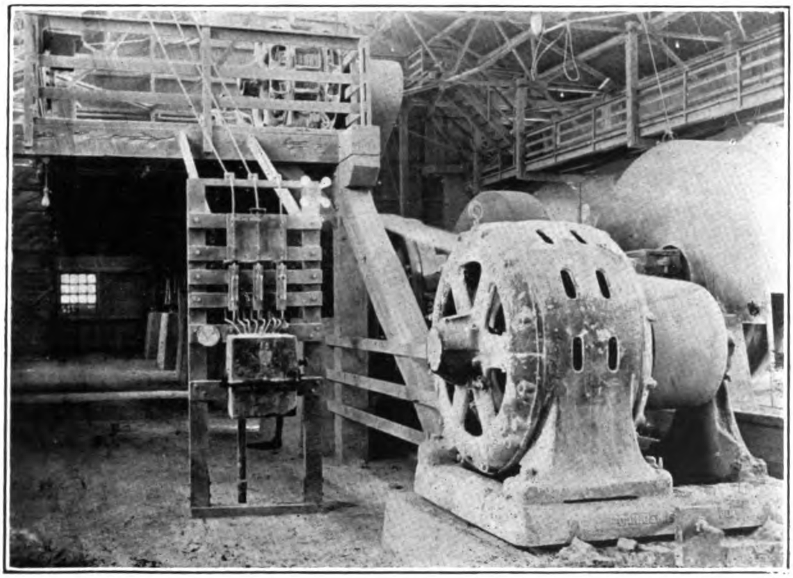

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FIG. 8.—TYPICAL MOTOR CONTROL PANEL WITH FUSES.

has found to be the case in many instances. This is largely impossible in the cement industry, but it is the prevailing spirit in the industrial world at the present time, and is found to a small extent in this industry too. The electrical manufacturer has himself to blame for this condition of things, and deserves all that is coming to him on this account.

The only way to deal with cement mill troubles is to go about hunting for them, and to kill them off in their early youth, before they have time to amount to anything. This, in plain English, spells inspection, and rigid inspection. Where there are motors, there are bearings, and when the motors are induction motors, there are also air-gaps, which though small, are of an importance not at all in keeping with their physical dimensions. Hence, all motors have to be gone over regularly and checked up with the air-gap gauge. One thing which must be avoided is allowing a rotor to run on the stator, through worn bearings. When this once happens, the characteristics of the motor have been modified to a greater or less degree. Not only is excessive leakage set up, owing to the damage to the iron of the teeth, but local heating is also the result, which makes itself apparent in the frequency with which coils burn out, due to eddy currents in the iron where it has all been wiped together. This inspection therefore, must not be left to take care of itself in any haphazard way, but it must be part of someone's regular routine, from which no deviation can be permitted. It should also be pointed out here that motors should have bearings that can be adjusted to take up the wear, by keeping the rotor central. Mere large air-gap is not enough, for, when once the wear starts, it is very rapid after it has gone a few mils, owing to the unbalance in the magnetic circuit, the difference in pull being proportional to the square of the reduction of the air-gap.

Then again, the switchgear must not be neglected. This is also subject to wear, which must be watched regularly. The auto-transformer switch contacts are subject to more or less severe service, and, unless they are attended to regularly, there will be trouble. Some cases have come under the writer's notice where explosions have occurred inside the case, owing to an accumulation of oil gases, given off through overheated contacts, becoming ignited and blowing the case cover to bits. The connections on the motors, and also the connections inside the starter case, should all be examined, as they work loose, and will give trouble unless attended to right away.

Another source of trouble is the fuses; only one make that the writer knows of really indicates when the fuse is blown, with certainty, and it is no uncommon thing to find motors in consequence running on one phase only, owing to the fact that the fuse indicator has not worked. The fuses are generally much too large for the motor, and, therefore, if the motor is running nearly up to full load, there is sure to be a break down, if this happens in hot weather, when running on one phase. If oil switches are used, they must be regularly cleaned to ensure them operating when wanted, and they should be tested now and again to see if they will do what they are intended to do.

The personal element, here, as in other things, enters so largely into the successful operation of the electrical equipment that a word or two may be allowed on this point. It is essential to have one good man in charge of the electrical work in a plant of this description, who is a thoroughly practical electrician, and he will be none the worse if he has a fair technical knowledge. In addition to seeing that all repairs are properly made, he should be able to take an intelligent interest in the general power problem. This is necessary, not only when power is purchased, but equally so when the plant generates its own power, from steam or water. It is only when one is paying the power bill to someone else that the question of load factor and power factor is brought forcibly to the fore, but the need for careful attention to these items is none the less equally important when one is buying power in the form of coal. By maintaining a high load factor, great economies may be effected, and the question of power factor has considerable bearing on the regulation of the voltage, and the efficiency of the generators.

Then, again, he must be quick to see defects in the apparatus which he has in his charge, and to remedy them as well as possible to meet the conditions under which they are working; there are always plenty of opportunities for him to display ingenuity in assisting the superintendent in the operation of the whole mill. If he runs his end of the business well, his staff must necessarily have a fair amount of time to spare, which he can profitably employ in making improvements in his department, which will make for more efficient operation of the mill as the whole. As in all other positions of a like nature, it pays a firm to have a good man and to pay a good price for him. For assistants, he should have one really good armature winder, who can work rapidly and at the same time make a good job. When a motor is burned out

for any reason, it is essential that it be repaired as quickly as possible, even though a spare one is on hand, as it may be wanted the next day. He should also have the choice of any spare handy men who are about the place, to train them as motor tenders and general repair men. They do not require to be highly skilled men, as their principal job is looking after bearings, renewing contacts on starters and switches, and repairing arc lamps. They need to be careful and intelligent men, who will take an interest in their job.

As regards the illumination of the mill, little need be said. There is not, as a rule, much scope for the arc lamp, owing to the number of overhead bins, etc., but they should be used wherever possible. They are generally expensive to maintain, owing to the dusty atmosphere, and seldom work really satisfactorily. In any case, it will be necessary to have a large number of incandescent lamps; these are required at all gear points, and at the feed spouts of machines and in conveyer tunnels and monitors. It will be found necessary to provide some form of locking guard to avoid loss through wilful breakage, and also theft, which is very common in some districts, where a regular trade is carried on in them. A liberal provision of sockets for hand lamps should be made, for the use of the repair gangs. It will be found the best policy to avoid all dark corners, as these offer such good opportunities for loafing during the night shift.

The lighting of the quarry is a difficult matter, as there is much damage done to electric lamps and wires through blasting, which generally occurs every two or three days. If arc lamps are used, it will be found necessary to provide stout boxes into which they must be dropped before a blast is let off, and thus they are saved. The principal damage is done to the leads, which require attention every time a shot is fired. Owing to the constant change in the position of the lights, it is not possible to run the wires underground. They are sure to be hit by a piece of rock, even though nothing else in the neighborhood appears to have been hit. Even when they are put underground, they suffer considerably from large pieces of rock falling from a good height. The writer would be glad to hear the experiences of other men on this question. It almost seems that the oil flare light is the best solution of the quarry lighting problem. Projectors have been suggested but the writer has no experience with them in this class of work. Outside of the quarry, there are no other points in the mill that call for special mention as regards lighting

In conclusion, I would say to the designer of mills of this type that adequate povision be made for the foundations of all motors, as vibration is fatal to long motor life. Accessibility must at all times be the chief aim, as a motor that it takes some trouble to reach will generally be neglected. Also, in purchasing equipment, care must be exercised to choose a good robust motor, yet to see that the weight is properly utilized. Mere weight counts for very little in a motor's favor, and is much against it when it comes to handling it for repairs, or moving it about for any reason. The experienced man will see that his vital materials are well designed, but that the ratio of the iron losses to the copper losses is not too high. They should be about equal, giving, not a cheap motor, but one that will have a high output in comparison to its weight. After this, there should be only enough material to make the frame rigid. More than this is mere waste. The mechanical details should be well looked after, and, in addition to this, each motor should be well inspected before leaving the maker's works. It therefore clearly follows that it will pay any firm to employ a good industrial electrical engineer to advise them on the types and sizes of the motors to install, and to put through their motor contracts for them, and see that they leave the maker's works in good condition. There is no more reason for an untrained man trying to do his own electrical engineering than there is in the ordinary man trying to design his own house and dispensing with the services of a qualified architect. The actual results are about comparable in both cases.

DISCUSSION ON "ARC VS. TUNGSTEN STREET LIGHTING IN SMALL TOWNS" (STEPHENS), PORTLAND, ORE., APRIL 16, 1912. (SEE PROCEEDINGS FOR MAY, 1912.)

(*Subject to final revision for the Transactions.*)

Gano Dunn: It is a deep satisfaction to see that the author of this paper has found in the Institute the forum where it may be presented and discussed instead of finding that forum in the Illuminating Engineering Society. The author followed good precedent. Illumination has been a close cousin if not a nearer relative to electrical engineering, and I think it always will be.

The general features of the paper indicate that the various qualities of illumination as presented differ from each other principally in the arrangement of units, in the methods of producing illumination, rather than in the electric means devoted to the actual creation of the light. When we get illuminants down to two-tenths or three-tenths of a watt per candle power we are arriving at an efficiency which used to be regarded as heralding the approach of the days of cold light. We have passed through, in recent years, marvelous improvement in incandescent lighting, with the practical doubling of the efficiency of illumination by the introduction of the tungsten lamp, and its influence is not yet fully realized, for the public is hardly yet aware of what has happened.

It is very natural that the two forms of illuminant should compete with each other. My prejudice—we all have prejudices—in fact, as a celebrated university president has said, most men feel instead of think—my prejudice is in favor of small unit distributing sources of illumination as against large units concentrated. But to show how neither one of these is the correct illumination for every case, we have only to read the paper very ably prepared by Mr. Stephens.

The psychology or physiology of electric lighting is the direction in which perhaps the greatest improvements have been made recently. The arc lamp has always been a lamp of high efficiency and power, but the flaming arcs have made no more rapid advance in arc lighting than has the tungsten lamp in incandescent lighting, so it is about right to say that the race is approximately even between the two types of illuminants. On the physiological side we find the law referred to and a general recognition of the fact that the very brightness of a light often contributes to make us think that the illumination is bad instead of good. An intensely bright light in a room depreciates the value of the illumination in practically every part of the room except the particular part it occupies. It is a realization of this which has led to such expedients as frosting the globe, the use of groups of small units, as in cove lighting, and indirect lighting in general, also tubular lighting, and is exemplified by the Moore system.

I once made a technical examination of the Moore system and was astonished to find that the illumination did not vary inversely

as the square of the distance. At first sight this looks like an inversion of the laws of nature. The reason ordinary illumination varies inversely as the square of the distance is that it proceeds from a point. The Moore light and other tubular systems, including incandescent lamps that are strung out in the form of tubes, may be regarded as sources in which the illumination proceeds from a line instead of a point. Its intensity then is inversely as the distance instead of inversely as the square of the distance.

I would call the attention of the members to a feature in the paper which may interest them. You have probably noticed that the engineering data, rates, volumes, etc., are followed in parentheses by their metric equivalents. Some may think this is not necessary, but I should like to tell what was done at the International Electrotechnical Congress in Turin last September. So greatly appreciated was this practise instituted by the American Institute of Electrical Engineers in giving metric equivalents in parentheses, that the Congress as a whole unanimously passed a resolution expressing its appreciation of the custom of the American Institute of Electrical Engineers and recommending that all electrical societies using English measures follow the same course. It is little realized how much our papers are read abroad, and it is also little realized how vastly important that little parenthetical item in the paper is. For the Englishman that is not accustomed to American things, it is difficult to read an American paper. This seems a radical statement, but I have many times had evidence of it. For instance, on the question of weight. The English ton is not our ton, our hundred-weight is one hundred pounds while the English hundred-weight is one hundred and twelve; the English gallon is not our gallon and the English bushel is not our bushel, and so it goes on down the line. When an Englishman not familiar with these facts reads a paper of the American Institute of Electrical Engineers, the metric values enable him to know exactly what the author means. I went so far once as to be rude enough to break into a conversation of British engineers in a train from Manchester to London. I heard a British engineer complain of American engineers for false statements as to the delivery of American pumps which, he asserted, were constantly overrated. I called his attention to the fact that he was probably measuring the pump in English gallons and explained that the American gallon was only 83 per cent of the English, owing to the adherence of the Americans to the old English standards.

S. C. Lindsay: I wish to take exception to one statement made in Mr. Stephen's paper regarding the tungsten post system: "The light from the lamps is therefore constantly in the line of vision and produces a glare effect in the eye that from the standpoint of good illumination is extremely objectionable. The general effect on the public may be pleasing at the start, but experience shows that after a short time the novelty wears off

and general dissatisfaction prevails." That may be true in some cases where cluster lamps are not properly arranged and distributed on the street. I would like to have the author of this paper visit Seattle and look at the lights on the streets of that city. I think he would then change his mind. I think Seattle has the finest example of street illumination from posts and cluster lights that there is in the country. I have not seen the cluster-lights in all other cities, but have seen three or four other examples, and do not see how it is possible to improve on the Seattle cluster lights. I will go further and say the cluster lamps in Portland are not one-third as good.

F. H. Murphy: I wish to ask a question as to the spacing and the height of the cluster lamps of Seattle. I am not familiar with them, only having been on the coast a short time.

S. C. Lindsay: I have no data on that point; the city owns the plant and the situation and arrangement of the lamps are entirely in the hands of the authorities, and I do not happen to have the data. Mr. Howes advises me that they are about one hundred feet apart and I should think from general observation that that is correct.

A. A. Miller: I can give you a reference which you might like to look up. About a year ago last January there was a paper presented before the Seattle Section on the subject of "Seattle Street Lighting" by two university students who made that the subject of their thesis. You will find it in the files of the *Journal of Electricity, Power and Gas.* The characteristics of the lighting system are there given with the spacing of posts and number of lights per post. In the downtown section they use a five-ball cluster arranged in an inverted V, with the point at the top, claiming that the distribution of the light in the street is better that way than if arranged in the form of a rectangle or otherwise. In the second-class district, according to the classification in Mr. Stephens' paper, they use a three-ball cluster and in the parks of the city a single ball is used. I do not remember the candle power of the units in the different clusters; that is all given in the paper referred to. The height is, I should say, approximately 15 ft.

Gano Dunn: One statement in the paper that attracted my attention, was the one in regard to the glare from tungsten clusters, which has been already questioned by Mr. Lindsay. I doubt whether it is a discriminating statement. If you have a cluster of tungsten lamps, say, one hundred feet away and twelve feet high that gives a brilliancy that is going to be no more in the line of vision than the brilliancy of an arc lamp two hundred feet away and twenty-four feet high and four times the intensity. I do not think the case made out against the tungsten lamp is a good one in that respect.

F. H. Murphy: I would like to call attention to another point in the matter of cost. The statement was made in the paper, I believe, that the cost in small units is greater on account

of the greater number of posts. It is true, of course, that in order to give the proper lighting by the flaming arc lamp, or luminous arc, it is necessary to hang it considerably higher, which of course requires more expensive posts and will partially counterbalance the cost of the greater number of small posts. I think that ought to be taken into consideration in making a comparison of the costs.

H. M. Friendly: I would like to make a few remarks in reference to street lighting by means of tungsten lamps within the business section of both small and large cities—remarks that are not at all technical, but more from the point of view of the ordinary citizen, the man who pays the bills.

It has been the custom to mount these lamps in clusters on posts. Where the streets and sidewalks are narrow it gives the effect of narrowing both the street and sidewalks, and the posts do seriously obstruct the latter. The pedestrians must keep within the inner line of the posts, and these are usually set about eighteen inches from the outer edge of the walk, thus, in effect, reducing the sidewalk width by that much.

It appears to me that an artistic and ornamental bracket of some kind could be easily designed, having a graceful downward sweep that would be readily adaptable to any buildings such as would be found along a business street, and then mount the tungsten clusters pendant from the outer end, which could be on a line with the outer edge of the walk. The lighting distribution would be quite as good as from posts, and the fixtures would be far less noticeable during the daytime.

The arc lamps with their relatively few posts at least do not obstruct the sidewalks so seriously. In the Portland business district, the tungsten lamp posts are a nuisance.

G. R. Cooley: It sometimes seems that the cost of installation of cluster lighting is only a minor consideration. We found in Seattle that the property owners were very willing to stand all this cost themselves to be able to have this particular style of lighting, and it became necessary for the City Council to refuse to let the property owners put in cluster lighting because the council could not see its way clear to furnish the current they wanted. The people were so much taken with this system of cluster lighting that they were anxious to have it, and it was even put on streets where there were no buildings for blocks and blocks at the sole expense of the property owners. The council had to cut out some of the lights because there was no necessity for them there. We use the frosted ball with a tungsten light and have had no difficulty, and as Mr. Lindsay said, we have a perfectly installed system.

W. A. Hillebrand: The title of Mr. Stephen's paper is "Arc vs. Tungsten Street Lighting in Small Towns." I wish to refer particularly to small towns and especially to conditions on the Pacific Coast. The smaller towns in the Northwest are of recent growth, very recent compared with the smaller towns

in other parts of the country. The town has to pave its streets, provide sewers, sidewalks, water systems, curbs, parkings, etc., and I think you will find that in some places the taxes run as high as four per cent. A system of ornamental street lighting is simply adding another expense. It seems to me that this matter ought to be carefully considered.

The influence of a city like Portland can hardly be over estimated in its effect upon all the small towns within a radius of one hundred miles. For instance, I fully expect to see a gradual and steady increase in the amount of tungsten post lighting in the smaller towns throughout the state, simply because Portland uses that system extensively. A conspicuous example is a little town about forty miles up the valley, through which you passed on the road. I don't know what the per capita cost of such a lighting system comes to, but it seems to me that it is highly questionable whether the average town can afford lighting of that nature.

R. Howes: I wish to bring out one point that I do not think has been touched upon regarding the lighting of Seattle. The clusters on the main avenues consist of five lamps, one above at the top, and two a little lower one on each side, and two more still lower, one on each side, and the clusters are spaced opposite each other, that is, both sides of the street are lighted. I do not remember the exact distances between clusters, but I think it is about one hundred feet—not more than that. This arrangement of five lights prevents the casting of any shadows on the street by nearby poles and other structures, whereas the concentrated light of arc lamps casts dark shadows on the street. I think that is one reason why the Seattle lighting is so attractive to the people that come there.

If strong lights are placed only at the intersections of streets, they light up the crossings for approaching vehicles.

If the same amount of light were distributed uniformly along the street, I think that advantage would be somewhat less.

Gano Dunn: You mean that you like the spot light at the street corners better than the distributive illumination?

R. Howes: No, but I mean it brings out the crossings to the people riding along the street. While they may be blinded at a distance, as they approach the light and pass under it they can see on either side. If arc lights are distributed uniformly along the street without regard to the crossings, as is done in some places, the benefit of this effect is lost, just as with distributed tungsten lights.

George H. Sampson: The last speaker spoke about putting the arc lights closer. Where the street car systems have poles in the center of the street, the arc lights are put on those poles, and it gives a very fine average distribution. I should say it means about 100-ft. spacing.

J. B. Fisken: I hoped when I saw the title of this paper that there would be quite a discussion on the lighting of small towns.

We have heard something about the lighting of small towns, particularly Seattle, and Portland and San Francisco, but there are other small towns that we have not heard much about. I agree with the author that enclosed carbon arcs are practically obsolete. I can endorse that statement because our own town is lighted that way. It happens that we have a contract calling for 500-watt arcs which cannot be changed until that contract runs out. Another statement of the author's I thoroughly agree with, that it is impossible for the average man to know what it costs a municipal plant to do lighting.

The company I am connected with has the distribution system in two small towns at present and expects in future to control some more. We bought a plant at Colfax, a town with population of four or five thousand, that is, we bought the existing plant. It was lighted with arc lights spaced at irregular intervals, and of irregular illumination. The people were very much dissatisfied and when we bought the plant and applied for a franchise we took the opportunity of getting a new street lighting contract. We took it on the basis of a series of tungsten lighting system, the lamps being suspended across the street intersections. I don't remember the details of the contract, but we had a certain number of 250-watt tungsten lamps spaced about 300 ft. apart in the business part of the town, and on the outskirts 100-watt tungstens at reasonably close intervals, not very close, but fairly well spaced. The approval which the new system received was very gratifying. We had a great many citizens come to us and say how pleased they were with the change. We didn't have the brilliant spots, but the street looked well lighted. In another small town of about eight hundred inhabitants, where we installed these lamps, we followed the same plan and it has been very satisfactory. I would like to hear from any who can give experiences in other small towns.

A. A. Miller: There is one point that I do not think has been brought out, with reference to the "fenced-in" appearance of the street when it is lighted by tungsten posts. All depends on the point of view. The smaller towns to which this paper applies invest a certain amount of money in street lighting systems. I think the average citizen rather than feeling a sense of being fenced in, feels a sense of pride in being able to see in what he has invested his money. If one goes into a small town at night and sees a pleasing illumination of the main street by post tungstens it has a certain effect in raising one's estimation of the progressiveness of that town. In the daytime that "fence" is in evidence, but I do not believe that it is displeasing. There I do not agree with the author. In a large city, where ordinances have been directed against poles carrying overhead wires, which ordinances resulted in underground distribution, that might apply. But even in our largest cities, where the wires have been put underground, I do not think the effect of a long row of well-proportioned tungsten posts is unpleasant to the eye, especially at night.

Alexander Martin: I have had some experience in the last few months in connection with street lighting in several small towns in eastern Washington. Three of them, particularly, I would like to speak about—Pomeroy, Dayton and Kenewick, Washington. I found that in all these towns, under the old system before reconstruction they had 16- or 32-c.p. multiple lamps connected to the secondary system. In reconstructing the systems in these places, we replaced them with 6.6-ampere series tungsten lamps. At Kenewick we are using 80-c.p. at Dayton 60-c.p. and at Pomeroy 80- and 40-c.p. series tungsten and four series arc lights on the main street. In Dayton the city has placed 31 three-light posts on the main street, covering a distance, as I remember it, of about a thousand feet. This gives very satisfactory illumination for the main street. In the placing of the series tungsten lamps we are using a five-foot bracket and putting the poles on which the brackets are hung at the curb corners, the brackets coming out over the street at an angle of 45 degrees; the brackets are placed at a distance of about nineteen feet above the ground. We are using the Cutter type of reflector made for this work, and find the results very satisfactory.

The important consideration in all these towns is the expense. There are very few of them that could afford much cluster lighting, and unless the business interests and people get together and carry most of the burden, the city cannot consider it. When it comes to placing the smaller lamps on the street for general illumination, they are able to do it, and find it gives satisfaction, and good lighting effects. In hanging these lamps, if you have an alley distributing system, it becomes necessary to have extra poles to take care of the brackets. With a series tungsten system, such as I have been describing, we use 30-ft. poles on the street corners, where there are no other lines at the present time, or are likely to be in the future. This is governed by local conditions. In other places we have to install longer poles in order that additional lines may be run at some future time. Where there are lines already on the street, we place the poles so that we can use them for the street lighting brackets as well. For the small towns it seems to me the best thing is the series tungsten lamp. I believe we get better results for the money spent, and it keeps within the limit of expense to which the average small town can go. While it is possible to place cluster lighting on a few blocks of the main street, they cannot indulge in much of it because of the expense.

O. B. Coldwell: The company with which I am connected has service lines in a number of small communities, and it might be of interest to state that in a number of them what we would now call the old-style series alternating lamp is in use. The merchants of the most progressive of these communities have, during the last year or two, been following the lead set by Portland, as stated by one of the previous speakers, by clubbing

together and raising funds for putting in post lighting. I do not believe that in general, however, there is as strong a tendency to use post lighting for street lighting purposes as there is to install series tungsten lamps. I believe that for most of the instances I have in mind the series tungsten lamp works out to a very good advantage and perhaps is the best general system for the purposes of the small community. Conditions must always govern and the needs of the community have much to do with it.

In his paper, the author makes mention of one point which I think should not be overlooked in this discussion, and that is the possible improvement which might be brought about by taking care of the glassware on these tungsten fixtures. Some tests which have been made here in Portland within the last year or two have shown very marked improvement from the cleaning and taking care of the glassware. I think increases in illumination as high as 40 per cent have been obtained by simply cleaning off and dusting the glassware without even washing it. I think that Mr. Murphy could give us some figures on that point.

F. H. Murphy (by letter): In response to the suggestion of Mr. Coldwell that some of the members might be interested in the results of our investigation, I will state that the special test referred to was made in a drafting room lighted with tungsten lamps. The installation was not an exception in any way, but had the usual amount of care given to it in keeping it clean. Following complaints in regard to the lighting, we made careful tests on the plane of the drafting boards and found the average illumination to be 2.32 foot-candles. After dusting the installation we made a second set of tests at the same points and obtained an average illumination of 3.21 foot-candles, showing an increase of 38 per cent. Had the installation been washed instead of dusted it would undoubtedly have increased the illumination from 2 to 5 per cent more. We then replaced the installation with new lamps of the same wattage as the old ones (which had burned for considerably over 2000 hours) and a third set of tests gave us an average illumination of 5.52 foot-candles, showing an increase of 72 per cent over the dusted installation and 138 per cent over the installation as first tested.

Lloyd D. Gilbert: I am at present designing a cement plant at Oswego. I never had much experience in city lighting, but this is the fifth cement plant I have designed, and I have to take care of a good deal of outside lighting. On the El Paso plant we decided to cut out arc lamps and use tungsten for outside lighting, and we installed, I think, sixteen clusters of four in a cluster, 250-watt tungsten lamps. After trying them about eight months we had to discard them on account of the enormous maintenance. It was simply impossible to keep lamps in the sockets. It even took more time to put in new lamps than to trim arc lamps. So after running eight months and keeping close tab on the cost of ma ntenance, we decided to discard the tungstens and put in

arc lamps. I do not have the cost data at hand, but I remember very well that I figured at the time that I could buy the sixteen arc lamps and more than save their cost in a year, allowing a certain sum of money on each of the arc lamps for maintenance and for the trimming. The country about El Paso is very windy, and we tried every known method of supporting the lamps on the brackets and suspended them various ways, but nevertheless they would get jarred enough to break the filaments, and at last we had to discard them.

Gano Dunn: What capacity were they?

Lloyd D. Gilbert: Most of them were 150-watt, four in a cluster, in series on a 440-volt line. We had a few 200-watt lamps. What we intended to do was to have the clusters of four take the place of arc lamps; we spotted the poles here and there around the plant where convenient. We also tried a few single lamps inside, but the jar of the machinery caused their failure and we had to discard them.

Gano Dunn: A negative experience like this is interesting. I think the members here would like to ask Mr. Gilbert when it was he did this. I once had some experience in my own house, where I found it was costing me a great deal to use tungsten lamps. Then I was asked to try some new lamps brought out by two different companies, and I did try them. That was a year ago. I have not had a single one break since. Because there is so much difference in the manufacture of the older lamp and the new lamp, it would be important if Mr. Gilbert would state whether or not the lamps he speaks of were made within the last six months, or when.

Lloyd D. Gilbert: They were made over a year ago. About January, 1911, was when we decided they were a failure after an eight month's trial. I had been determined to make them a success in order to get rid of the arc lamp, which gave us more or less trouble around the plant, on account of the dust and smoke, but after giving the tungstens a fair trial, we decided that they were a failure. Our cost would be, some months, $80 to $85 for lamps alone, which absolutely prohibited the use of them.

O. B. Coldwell: I think that perhaps Mr. Gilbert's experience at El Paso was a little out of the ordinary in that the installation of four lamps in series on a 440-volt circuit, especially lamps of the 150-watt type, should be different from the ordinary installation as practised in city street lighting, or even in store lighting or elsewhere in the city, his plant being an industrial plant with a type of circuit adapted to the motors operating the cement mill. I believe the manufacturing companies now supply special lamps for series lighting and for multiple lighting, making a distinction between the two. Whether they have gone so far as that to make that distinction in lamps of the candle power or wattage Mr. Gilbert used, I do not know. I know that in the case of small lamps for sign lighting they make the distinction, and I have an idea that had Mr. Gilbert's

installation been made within the past few months, his success would have been much better.

F. H. Murphy: I have observed many tungsten lamps that should have broken long before they did for the benefit of the consumer. Tungsten lamps have a rated life of 1000 hr., but I find many installations that have actually burned 3000 hr., which would hardly make them seem excessive in cost, and I have found that to be true, not only of the newer type of lamp, but also of installations of the former type pasted filaments.

A. A. Miller: I would like to ask Mr. Gilbert whether or not these lamps were pasted filaments or the wire-drawn filaments.

Lloyd D. Gilbert: I cannot tell you now; I know that I got the best tungsten lamps that could be obtained at that time, and I believe they were wire-drawn; I am not certain.

J. B. Fisken: There are two things that occurred to me in connection with this matter. I heard recently of a case where rapid destruction of tungsten lamps had been traced to a feather duster, and there was no question about it. The charwoman of a school was in the habit of going through the school rooms and dusting off the lights, and the lamp breakage was very great. That was one case. In our own practise, we get some very peculiar results in summer, when it is very dry. We were installing a distribution system in a small country town and, although the nearest live wires were twenty miles away, the wires would get so charged that the men could hardly work on them. That is the second case. It seems to me that there might be a connection between those two. If the dust were highly electrified, then, in turning on the current, there might be a strong attraction of the filament to the dust-covered bulb which would result in the complete destruction of the filaments. I do not know whether Mr. Gilbert's filaments were simply broken or completely destroyed.

Lloyd D. Gilbert: Most of them were broken. Sometimes the globe would be turned black, when part of the filament had been jarred off. In most cases the filaments would break, simply cease to burn. We found the main cause to be the jar of the wind. You know it is a pretty windy country down there in Texas. They say down there that it blows so hard it blows the chickens up against the barn and starves them to death. For a system of lighting plants in a windy country, I do not think you can install tungstens and make them work.

Gano Dunn: I saw some wire that was about the size of human hair, and was cautioned against trying to break it because it would cut like a knife. It had a tensile strength of over 6000 lb. to the square inch and that wire was a tungsten; it was slightly alloyed. It is hard to realize that a substance so marvelously strong and slightly alloyed and even when not slightly alloyed so enormously hard as tungsten is, could be so weak under the circumstances in which it is used in a lamp. The tungsten filament has just gone through a stage in its manufacture from a process by

which the earlier lamps were made and under which they were almost useless for practical purposes to a process which has made them wire-drawn filaments, which in the opinion of practical men has increased their working strength ten times. It also has decreased their cost, and I should greatly deplore seeing tungsten lamps discarded or their use discontinued on account of the weakness of the filaments. I regard it as a temporary stage through which they have already gone and I believe that if Mr. Gilbert should make his installations now, he would not have that trouble.

R. Howes: The series lamp is usually a low-voltage lamp, whereas in using a multiple lamp there is a smaller filament of much greater resistance, so that I do not think 110-volt lamps used in a series should be compared with the tungsten lamp ordinarily used in series lighting, where four or six amperes are used in the circuit. I was recently asked to advise a small town up on the border in Washington, and upon learning the amount of money they had provided I found there was nothing that could possibly be gotten with the money they had and provide the number of lights desired, except series tungsten lamps, and they had to use 40-watt lamps, at that. Regarding the case given by Mr. Gilbert around a cement plant there is a great deal of noise, which is a type of vibration, and while it might not affect, very much, people that are in the habit of living there, at the same time a new arrival notices the great amount of noise, and probably the sensitive filaments also are affected by it to a very large extent.

A. G. Jones: I would like to ask Mr. Dunn if the wire that he referred to as being so strong that it would cut the hand, had had a current passed through it. My idea is that after the tungsten has been burned several hours, it materially weakens, and after current has been passed through it several hours it is very delicate.

Gano Dunn: The wire that I spoke of had not been used. It was wire to be used for mechanical and not electrical purposes.

A. G. Jones: I had a piece of tungsten filament that was intended to be used in a 110-volt lamp and attached it to a chair of average weight, and it lifted it up without any trouble, but if you should attempt to take a filament out of a lamp that has been sealed and is ready for use, you would probably break it which would illustrate the difference in tensile strength after it has been used.

Lloyd D. Gilbert: Another word regarding the installation I spoke of. We had a number of single lamps working on a 110-volt circuit. We had ten or twelve departments and we had one over each one of the doors at the main entrance. These lamps were supported on a gooseneck made of 2½ in. pipe. We also had probably a dozen and a half of them working singly on the 110-volt circuit inside. It was either the noise or the vibration from the winds that caused their destruction. All

behaved alike. Almost every evening when we would turn on the lights there would be four or five out. And we had good regulation on that circuit, with no variation to speak of, as we had our own power house in which we had installed two 750-kv-a. steam turbines, with automatic voltage regulator.

L. B. Cramer: We are using tungsten lamps for train lighting, principally as an experiment at present; our trains are run over city streets to the terminal and cross about twenty street-car crossings in running over the last one and one-half miles of track. There is a considerable jar at some of these crossings, but the wire-drawn filaments in the tungsten lamps that we are using have sufficient strength to withstand shocks of this sort without breaking. We are using 120-volt lamps, five connected in series.

For this reason I am inclined to believe that there is something else back of the trouble that was experienced at the cement plant, other than a Texas wind.

Gano Dunn: I might add that just before I came away from New York the superintendent of motive power of the subway road in New York, Mr. Stott, Past-President of the Institute, told me that after running for some time, the tungsten lamp proved a great success, and practically no difficulty was found in maintaining the lamps. They gave enormous advantages from the point of view of good illumination. I think the figures were something like this: with a 10 per cent drop in the voltage due to the starting of the trains, tungsten lamps dropped perhaps 20 per cent in brilliancy; with the same voltage drop the carbon lamp dropped, I think, 60 or 70 per cent; the difference could not be compared. The introduction of the tungsten lamps on the trains has given great satisfaction to the public, and they remain steady where the carbons used to drop out and break.

H. V. Carpenter (by letter): It seems to me that we need to recall the discussions which followed the commercial introduction of the telephone and, later, the wireless telegraph. Each of these was expected by many to displace the telegraph, but soon found a field of its own. The tungsten lamp has already proved best for the inexpensive lighting demanded in scattered residence districts and in small towns where a lower standard is acceptable, and also in the opposite field of high-class business district lighting where a decorative effect is desired both day and night. It is quite possible that the arc will hold its place in the large field lying between these two requirements, and the easy combination of arcs and series tungstens, on the same circuits, if desired, leaves little reason for choosing one to the exclusion of the other.

DISCUSSION ON "IRRIGATION IN THE SPOKANE VALLEY" (CORBETT), PORTLAND, ORE., APRIL 16, 1912. (SEE PROCEEDINGS FOR APRIL 1912.)

(Subject to final revision for the Transactions.)

J. B. Fisken: To show what electrical engineering has done, I might state that the first time I saw the Spokane valley was twenty-five years ago, and I don't think there were six houses in the whole 35 miles. The valley was covered with bunch grass, which was considered only good for the Indians to feed to their cayuses. I had a request from a prominent member of this Institute to make some inquiries as to prices about two years ago, and I found prices for irrigated lands ten miles from Spokane ran from $800 to $1,000 an acre. When I first saw it, I could have bought the whole place for $2.50 an acre. I say that merely to illustrate what irrigation has done in the Spokane valley, and to encourage others who have had a chance to exploit it. Mr. Corbett has omitted to show one thing on the diagram in his paper to which attention might be called. There is one place up there where there are arranged radially at the foot of the shaft four chambers, the idea being that one pump was all that was required to start with. That plant could have been quadrupled without any additional expense in walling the chambers. Mr. Corbett states that there is a rate at present of $4 per month, per kv-a. He does not state whether the charge is by the month during the irrigation season or the rate of $48 a year; the discussion on that point has not brought this out.

L. J. Corbett: That was for the irrigation season of three or four months, $4 a month for four months. Whether that holds for the balance of the year for the supply I am not sure. There are contracts in which that same rate does apply, but the smaller amount of power used makes the bill correspondingly less.

J. B. Fisken: That is four dollars a month for the four months used, or $16 per kilovolt-ampere per year.

L. J. Corbett: Four months.

Mr. Fisken: It would be interesting to the Institute if Mr. Corbett could give any data as to the life of this soil irrigated.

The Spokane valley has no great depth of soil, and is underlaid with a washed gravel. I have often wondered whether under the constant irrigation this soil would not be washed off, and perhaps Mr. Corbett has some data on that.

Mr. Corbett: I have no definite data on that but I do know some cases where the farmers did not understand irrigation methods and put on too much water, and did do a great deal of washing and brought the gravel up to the surface by washing the soil off the surface; but where the water is carefully applied there are no bad results up to the present time, and it is a question of farming and not of irrigation.

A. A. Miller: Mr. Corbett has described irrigation in the Spokane valley. As is well known, there are several other districts in Washington, which for the most part depend on a gravity sys-

tem of irrigation, namely, the Yakima and Wenatchee valleys. In both, however, electric power pumping is becoming more of a factor from year to year, and central stations and transmission systems serving those places are paying more attention to acquiring that kind of a load. In Wenatchee I happened to remember the rates applying were something like this, $5 to $7.50 per horse power per month for a period of six months, which would mean $30 to $45 for the period, no power being served such a load during the remaining six months of the year, the exact date, of course, depending upon the size of the motor installation. Mr. Fisken has mentioned the enormous increase in the prices of land incident to irrigation. In Wenatchee and Yakima, also, it is not an unusual thing for land to sell as high as $2,000 an acre. I have heard of it selling as high as $3,000. It can be capitalized, at whatever rate of interest one wants to use or with which he will be satisfied as an investor. One man, for instance, in Wenatchee, owned 40 acres. His returns from that in one season were approximately $40,000 so spreading that over a reasonable capitalized value, it results in a high rate of interest and you can see that it is very desirable to improve those places where it is necessary to run water up hill as President Dunn has very aptly stated.

The Chairman: Were those gross earnings or net profits?

A. A. Miller: Those were gross earnings, probably fifty per cent of that would be deducted, for cost of marketing and growing.

The Chairman: The question of load factor is a very interesting one on the cost of irrigation, and I believe it is one that should be well discussed. I merely suggested and I would be glad to hear a discussion on that.

J. R. King: I am connected with the selling end of the electrical business and the question of load factor to my mind, has a very large place. In Seattle now we offer very advantageous rates for " off-peak " service. We offer very low rates for this service, and have one rate there of eight and a half mils per kilowatt-hour, that is, for one hundred horse power, or over, connected. We prohibit use of the service from 4:30 p.m. to 8:30 p.m. I ask Mr. Corbett if it is not possible—he mentioned one place where they didn't have any reservoirs at all and another place where they never did any pumping at night—to pump at night and store the water. It seems to me in the face of those rates they quote, that it might be possible to install reservoirs and store the water at night, or early morning, and put it on the ground at night. It would seem that water would go farther at night when there would be no sun to evaporate it. I think it is the aim of every central station man to have his load curve as flat as possible, and they could pump from nine p.m. up until eight o'clock in the morning, and their power rates would probably be a great deal lower. There must be some reason why the electric company and the irrigation people do not encourage this operation and I would like to hear what it is.

Berthil Anderson: In listening to the discussion I feel that a comparison should be made between gravity system and the pumping system of irrigation. I lived some time in California in the orange district there, and the system was considered rather valuable there. A flowing well is worth, capitalized a thousand dollars an inch and the water was carried by ditches for quite a distance from Redlands to Riverside. The water had to be taken care of and irrigation was done there exclusively at night. The irrigator prefers a small stream in preference to a large one to be used. A soil that is a granite soil with a heavy stream on it, would wash the organic matter and the magnesia and the clay and the mica away, and leave the bare surface. The lower end of the tract would have a mud strata and the upper end of it would have the gravel, if a rapid stream was run on it. Consequently, from reading the paper I believe Spokane valley would need an efficiency engineer to straighten out its system. Four dollars a month per kilovolt-ampere seems to be rather high in comparison with other power rates given both here in this city and with those paid in Spokane for straight power rates. With a lower power price I believe irrigation could be extended farther. At this price the farmer is rather reluctant to install irrigation. From the high prices of irrigation, it is a fight between the irrigator and the company. I knew a man down there that guarded the gate with a shot gun, when water was needed. I believe the system needs some improvement in Spokane valley.

W. A. Hillebrand: Irrigation is valuable for what it produces. However, I think the electrical engineer has no right to take all the credit upon himself. To a man growing vegetables and perishable fruits proximity to a center of population is necessary. There is also another important factor that has not been mentioned, and that is the cooperative association for marketing and selling the products. An acquaintance of mine who owns a fruit ranch in the Rogue River valley told me that shortly after the organization of such a cooperative society, property values in that region doubled, which he attributed to the formation of this association.

Last fall a land show was held in Omaha, as they are held throughout all the cities throughout the middle west. At this show, products were exhibited from the lands west of the Rocky Mountains. A prominent feature being the apple exhibit. A horticultural expert, comparing irrigated and non-irrigated fruit, said that the product of the irrigated land had a finer appearance, the apple being more perfectly formed than that produced on non-irrigated land in the Willamette valley, but that the apples grown on the irrigated land were practically worthless in two weeks, at the close of the show, whereas those from non-irrigated lands were still in good condition. Furthermore, he said there was more naturally productive lands in the Willamette valley than in the states of Idaho, Nevada, Utah and a portion of Colorado,—grazing land excepted.

S. C. Lindsey: The question of irrigation is one that is intensely interesting to me. Thirteen years ago I came to the coast. I remember riding across Montana, Idaho, western Washington and looking at these barren stretches of land apparently fit for nothing, and when I arrived in Seattle I got into conversation with a man that had been living near Seattle for a number of years and discussed that great stretch of barren land in there. He said there was land in there he wouldn't have if they would give it to him, immense areas good for nothing, and since then this question of irrigation has developed and those valleys have been made very fertile by the use of electric power, and I often indulged in stretches of imagination with regard to that immense area on account of these vast stretches of land, and on account of the development of the water power plant, and the possibilities of irrigation by electricity. It seems to me I can see the tide of immigration rolling up against this coast, most of it coming to Seattle, of course, and then it will roll back into that valley, eventually making the Pacific Coast one of the most desirable, one of the most productive, one of the most fertile spots in the world. If the immense water power in the Cascade mountains, and in fact in this whole coast range were used for agricultural purposes, it will produce a future for the Pacific coast, which I don't believe will ever be equalled on the Atlantic Coast.

The Chairman: I like the note of inspiration and enthusiasm in Mr. Lindsey's remarks. I had occasion to study the water power statistics of the United States in going before the National Water Ways Commission as President of the Institute a few months ago, and I have on several occasions taken data from them, you, undoubtedly, being in a water power country are more familiar with it than most electrical engineers are, but when I realize for instance that there are, as nearly as can be figured, 27,000,000 h.p. produced from coal in the United States, and that at a cost of development that would approximate the cost of production of that steam power there are 35,000,000 h.p. of undeveloped water power, and that there is today only a total of 5,000,000 h.p. of developed water power, of which a very large part is in the state of New York, and made up of Niagara power; and when in connection with all that it is also noticed if you include secondary power, all these are primary, and include power at a cost of development from 25 to 50 per cent above the cost of development of steam power, there would be no less than sixty-seven million water horse power in the United States, and when on top of all this, you notice the significant statement that one-third of the whole amount is up in the northwestern corner of the United States on the Columbia river and its tributary districts, you will see there is no reason why this great flood of immigration will not come westward.

R. Howes: I ask Mr. Corbett if he has made any calculations on the cost of private storage and pumping the water on "off-load hours" so as to improve the load factor of the operating

companies. I was associated for a number of years with one of the companies in that district, and am fairly familiar with the water supply and the nature of the load. If he has figured it out and finds it is not economical to build storage tanks and pump the water during off-load hours, such procedure can hardly be expected for the present, but if it has not been figured out, I think it would be well for some of us to take time to figure it and see if it would not be a profitable proposition.

J. B. Fisken: There are different conditions that affect the question of load factor. When a power plant is located on a stream without storage, the load factor becomes a very important item. If on the other hand, there is storage, this load factor is important only as regards the capacity of the plant and not as regards the water supply; and I also want to state there is a certain objection to the irrigation load. Out in the west the streams go down pretty low in the summer and occasionally it is necessary to burn coal, and $16 per kv-a. per year is not a very big price to give for steam generated electricity.

L. J. Corbett: In presenting this paper I am acting as a chronicler only, and I am merely reporting what has been done in the Spokane valley in the way of irrigation. In criticising certain points in it I feel that you are not criticising me but the methods. They are subject to criticism, and I have called attention in the paper to a number of these features which have struck me in the same way they have you. I presented them without comment. I am glad to see them criticised.

The question of reservoirs and night pumping is one which could be worked out for better economy and for better load factors, and it deserves more attention in the valley. In regard to Mr. Howe's question I would say that I have figured on the cost of reservoirs in connection with systems in that locality. It was some years ago, however, when cement was higher in price than it is now. When I presented the figures for one project the directors of the company for whom I was gathering them did not feel like putting it in. Irrigation in this district is handled or financed by promoters. They are developing the systems as cheaply as practicable, the aim being to get the land on the market in salable condition, sell the tracts and get their money. Under these conditions, we have to compete with installations already in the field, and the unit cost must not be greater than that of the existing systems. The power bill is not so important to the promoting company, as the buyers soon shoulder that.

Irrigation is yet new in the valley, only dating since 1902, ten years ago, and there is a great variety in the methods of irrigating, and the cost per acre.

In regard to reservoirs, the porous nature of the soil as mentioned in the paper, makes it unadapted for reservoir bottoms, and some form of lining would be essential. This would make it expensive, and so the companies are slow to put in such works.

The systems now installed show in many cases extravagance in some respects, economy in others, and there is a great variation in the proportioning of the equipment to the land. This point has not been taken up in this discussion; the capacity of the pumps compared to the area of the land ratio varies much in these systems, and this has its effects upon the costs.

Costs per acre for installation, and yearly costs per acre have been given in other irrigation papers presented before the Institute, and a comparison will show that costs in the Spokane district are high. If the power companies and the companies putting the land on the market would get together more than they do at present, I think great benefit would be derived on both sides. I do not look for much in that direction, however, until the large companies have sold out their holdings and the buyers of the tracts gathered together as mutual companies continue the operation of the systems. Then perhaps a working basis can be arrived at which will serve to flatten out the load curve and lessen the power bills.

The question of water supply is one in which I think the Spokane valley is remarkable compared to other districts. I have represented in the sketches merely one recess in a well, and as Mr. Fisken pointed out there are wells which have two,three or four recesses to make room for equipment needed for additional pumps for irrigation or domestic supply.

DISCUSSION ON "AUTOMATIC PRIVATE BRANCH EXCHANGE DEVELOPMENT IN SAN FRANCISCO" (DEAKIN), PORTLAND, ORE., APRIL 17, 1912. (SEE PROCEEDINGS FOR APRIL, 1912.)

(Subject to final revision for the Transactions.)

H. M. Friendly: I ask if Mr. Deakin has ever considered the use of a private branch exchange having a limit of 170 stations instead of the 90 station limit in order to obviate having to use second selectors. In Chicago, I saw the switch that the manufacturers had designed, but I had no knowledge of its practical use. I also saw one at Columbus, Ohio, they were testing. The switch differed somewhat from the ordinary connector switch known as ten levels up and ten horizontal. This switch had twelve levels up and nineteen levels horizontal, in that manner you could obtain one hundred and ninety terminals. Of course, I assume Mr. Deakin would have to kill the top terminal, that is the naught level in order to facilitate intercommunication. I would like to ask if that kind of equipment has ever been figured on, and if it has been successful?

Gerald Deakin: It has been figured on.

A. H. Griswold: The problem of the private branch exchange service is probably as much in the lime-light today as any other telephonic problem, and practically all the telephone engineers are working along that line. Their desire seems to be to get a private branch exchange service which is intercommunicating as far as the company using the exchange is concerned, and at the same time will give proper service to the entire city or exchange. The combination can be made in a great many ways. The automatic service affords a very desirable intercommunicating device as far as the company, itself, is concerned, or as far as the service to the city is concerned. It also affords a splendid service, and to enter into a discussion of the automatic vs. the manual private branch exchange switchboard would take a long time, and at the same time, would be reviewing the subject again. So I think the things we must work on the hardest is to get intercommunicating service and at the same time afford all of the benefits of a proper service to the entire telephone using public.

A. H. Dyson: About the only thing I can say in connection with the paper at this time is that I believe Mr. Deakin has gone a long way towards solving one of the most important branches of the automatic telephone art. I have spent about nine years almost exclusively in the development of automatic switching devices for telephone service, and one of the most important and the hardest to satisfactorily solve has been the private exchange problem, and whether Mr. Deakin has succeeded or not, I am as yet unable to say, as I have not as yet analyzed his paper. The most serious aspect of the automatic private branch exchange is, or has been, the possibility of calls reaching the heads of the different departments when they should go to subordinates, which, when they do so, cause a great deal of inconvenience to the business man. In other words, they are called for trivial pur-

poses, trivial questions are asked, which occupy their time and detract from matters of more importance. I believe firmly that whether Mr. Deakin has or has not reached the proper solution, that if the automatic system prevails as the final telephone system, that all service, with the exception of long distance, I mean by that, long distance toll service, will be accomplished automatically, and further that a connection from one city to another city, regardless of geographical separation will be established with the assistance of only one operator. I am opposed in this view by some of the most prominent engineers, men who have given the subject a great deal of thought, in that the position they take we are tying up a system of expensive construction for an unnecessary length of time, that is preventing the use of the toll lines between intermediate points. I believe, however, a system will eventually be developed which will so operate as to enable the establishment of telephone connections between centers geographically separated at a cost less than is now required. Long distance connections as now established, at times, require seven or eight or more operators to extend a connection between two cities.

Mr. Deakin, I can say, from casually reading his paper, has given the matter a great deal of time and thought, and he, or his company, has gone to great expense to obtain these data, and I believe the Institute is indebted to Mr. Deakin for the information he has given us. I would like to ask the actual number of digits required to establish a connection between any points in San Francisco?

Gerald Deakin: Eight digits.

H. H. Dyson: I ask further what trouble is experienced by subscribers in calling a number of eight digits, in remembering the digits he is calling for. It has been my experience and observation that the ordinary telephone subscriber is unable to remember a number of more than four digits—I say a number of four digits, I will modify that by saying a prefix or affix of a letter or name, and four numerals. I ask if Mr. Deakin has made any observations along that line?

D. P. Fullerton: I don't know that I have much to say on the matter any more than to follow up Mr. Griswold's remarks. I agree rather strongly with Mr. Deakin's entire article. The trouble that meets us today in the telephone business is the rapidly increasing number of private branch stations and the increasing number of them effects the service seriously in that it puts a large number of people interested, or assisting in establishing communications over which the companies have no supervision, no control. So far as automatic apparatus is concerned, I do not know whether it is the right thing to use universally or not, but I agree entirely with Mr. Deakin that the private branch exchange, whether used universally or adopted for use with a manual system, is an admirable thing. I believe it is something that telephone engineers should give considerable thought to.

Probably Mr. Deakin has solved the entire problem, and I don't

believe he is very far from it, but I would say to the other telephone engineers to work on that one point and results will be appreciated by the telephone companies probably as much as any other development of the art.

R. W. Pope: I am here in this discussion not as a telephone man, but as the ultimate consumer and the victim of the telephone subscriber who insists on seeing the head of the department or speaking with him, and refuses to give any information to the exchange operator as to his wants. This has caused me infinite trouble and I see no way of rectifying it except through the education of the general public. I have been so unfortunately situated as to be a distance of 85 ft. from the answering office of our suite in the Engineers' Building. We find that the subscribers seem to be unwilling to state their business. If they would state their business, the operator would know at once who would attend to them. But instead of that, in my case for instance, they most always insist on speaking with the Secretary, and when they reach the Secretary, the Secretary would have to go to the office 85 ft. away or switch the subscriber on, in order to obtain such information as the present address of some one of the members. The office where the call is answered has that information right there, but as long as they will not state their business I do not believe it is possible to devise any system which will correct that evil. We must gradually educate the public as to the necessity of stating its business, when calling up in order to be properly attended to.

A. E. Burghduff: I don't know as I want to add anything to what has been said. I might give a short outline of the way our private exchange is conducted in Portland. We require a manual operator for each station. The user signals the operator if he desires a trunk or outgoing call. He then tells the operator who makes his connection in the ordinary way and when he is through hangs up the receiver and the operator disconnects the line. The intercommunicating line works exactly the same way you inform the operator of the local number you desire, hang up the receiver and she calls that number and when they answer she rings you and saves your time in that way.

One thing in the Secretary's talk stating that everybody wants the head of the department; not the head of the department but the manager, and with the automatic private branch exchange working entirely automatic, I see no way of preventing every one calling and getting the manager. It seems impossible to conceive of any device that will cure that, but in actual practise with the large per cent of these people talking to the operator, she can direct them to the right department even though they ask for the manager.

W. Lee Campbell (by letter): I have read Mr. Deakin's paper with a great deal of interest and profit. I wish to take this occasion to commend him and his company for the decided success which they have attained in the installation and operation of private branch automatic switchboard equipment in San

Francisco. The practise of the San Francisco company evidently has been developed to a point of high efficiency.

In connection with this paper I hope that a description of the automatic private branch exchange installed in the factory of the company making this apparatus, and connected by trunks to the public automatic exchange of approximately 30,000 stations and eight offices operated by the Illinois Tunnel Company in Chicago, Illinois, will be of interest.

This private branch exchange switchboard serves 100 individual line telephones and 12 extension telephones, and is equipped with 100 line switches, 10 first selector switches, 10 connector switches for completing local calls, three connector switches for completing incoming trunk calls, and three repeaters for outgoing trunk calls. The three incoming trunks each terminate in one of the connector switches, just mentioned, at the private branch board and in fourth selector banks at the Brooks office of the Illinois Tunnel Company. They are also equipped with repeaters at the Brooks office.

The three outgoing trunks each terminate in first selector banks at the private branch board, where they are equipped with repeaters, and terminate in regular line switches at the Brooks office.

Local or intercommunicating calls in the company's factory are made by using three figure numbers. These numbers run from 100 to 199. Outgoing calls are made by prefixing the Figure 2 to any number taken from the Illinois Tunnel Co.'s public directory. The purpose of the prefix is, of course, to put the private branch exchange line into connection with an idle trunk line to the Brooks exchange of the Illinois Tunnel Company. After that is accomplished the call proceeds in the usual manner.

Considerably over half the private branch stations, however, are not allowed to send or receive outside calls. Each employe, whose service is restricted to intercommunicating service, is automatically prevented from making outside calls by an attachment, which, whenever he calls the prefix 2, keeps him from securing a connection with the trunk, and gives the buzzing busy signal.

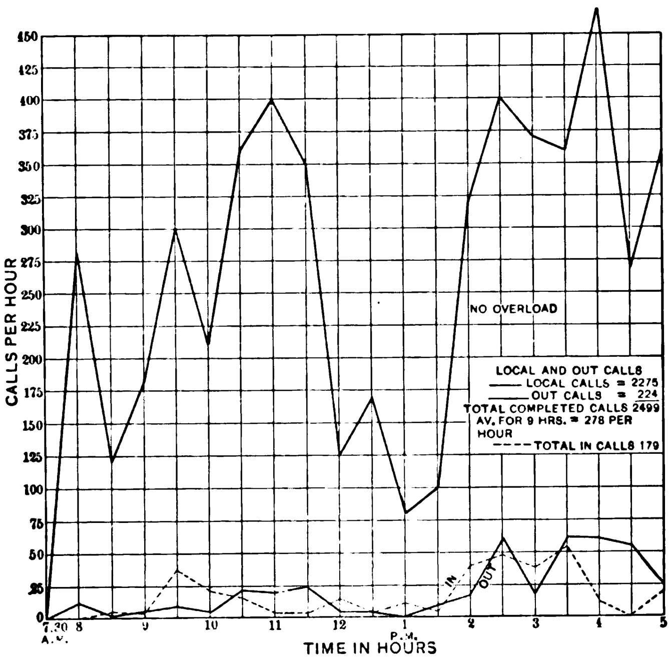
The numbers of officers or employees of the company, who are allowed to receive incoming calls, appear in the public directory with a prefix. For example, the number of the station which is locally 170 appears in the public directory 5891–70. A subscriber to the Illinois Tunnel Co's System, when calling 5891–70, operates a first selector, second selector, third selector and a fourth selector in the public system, when calling the first four figures of the above number, that is 5891. This puts his line in connection with an idle trunk to one of the three incoming trunk connector switches on the private branch board, so that when he calls the last two figures, that is 70, this connector switch is operated and extends the connection to telephone No. 70.

The automatic ringing interrupter, which serves the three

incoming connector switches, is arranged differently from that which serves the connector switches which handle local calls, so that when a local telephone is being rung on account of a call coming in from the outside, the party receiving the call is aware of the fact.

The circuits in connection with the three outgoing trunks, from the branch board, are so arranged that if one of the subscribers should attempt to make an outgoing call when one of the three trunks are busy, he will receive the busy signal so soon as he turns his dial from finger hole No. 2, which he does in attempting to secure a trunk.

The incoming trunks from the public exchange are arranged



in the same way; that is, if any public exchange subscriber calls 5891, when all three of the incoming trunks are busy, he will receive the busy signal.

The heavy load which a small automatic switchboard of this type carries successfully, and the high efficiency of small groups of automatic switchboard trunks, mentioned by Mr. Deakin in his paper, are attested by the curves in the accompanying figure.

One of these curves shows the intercommunicating calls per hour made from the opening of the factory at 7:30 a.m. until the closing at 5:00 p.m. Another shows calls per hour received on the incoming trunks, and a third shows calls per hour sent over the outgoing trunks.

It will be noted that the total number of local calls made during the day was 2275, the total number of out calls sent was 224, making the total number of originated calls 2499.

Between the hours of 3:30 and 4:30 p.m. (the busy hour of the day) the group of 10 connectors for completing local connections handled a total of over 400 calls, without being once over-loaded. Similar very high efficiencies are shown during the busy hours for the small incoming and outgoing trunk groups.

A number of busy hour local calls were timed with a stop watch, with the following results:

Time required to call	3.5	seconds
Time required for called party to answer	8.1	"
Time spent in conversation	30.1	"
Average time required for each connection Total	41.7	seconds

Lloyd D. Gilbert: Would Mr. Deakin consider an automatic installation superior to an inter-communicating system, we will say, for an industrial factory having twelve or fifteen phones, service, maintenance, and everything considered?

Gerald Deakin: With regard to the ability of the automatic private exchange to afford service equivalent in all respects to that given by the manual private exchange; early in the development of the commercial private exchange, we were fortunate enough to encounter a very large corporation, the officials of which objected very strongly to the receiving of or the making of exchange calls. As I stated in the paper, this objection was overcome by placing two bells on each line, one adapted to ring on exchange calls and the other on local calls. The officials of the corporation did not object to answering local calls, in fact they preferred to answer such calls. This system further permits the clerk or secretary of the official to establish the outgoing exchange calls.

It has been argued that the manual private exchange operator acts as an information bureau with regard to employees of the company by which she is employed, as well as an intermediary, and by so doing removes the burden of enquiries from other employees. While this condition may be true in many of the smaller systems, it does not always hold in the larger business organizations. For example, in any large concern, the operator could not be expected to know by name all employees and even if she did, she would probably not know the local telephone number of each. The result is, in actual practice, that many calls are thrown by the operator to the head of some department. The burden of locating the proper party and directing such a call to the proper number in case the call has to be changed, is then placed upon the called but not wanted party. Furthermore, the officials in a large corporation can rarely be obtained directly. Calls for them are nearly always intercepted by their clerk or secretary. In such cases as these the calling party is put to the annoyance of dealing with both an operator and clerk before

he can obtain the party wanted. I am merely citing these points to illustrate the fact that the objections which have been raised against the automatic system, are also applicable, to a considerable extent, to the present manual system. In an automatic system the extensive listing of numbers in the telephone directory, permits a large percentage of the total in calls to be made direct to the proper station. Those calls, which for one reason or another, cannot be made direct, can be made through the receiving cabinet.

Mr. Dyson made the statement, I believe, that toll connections could be more readily established automatically than manually. I agree with Mr. Dyson in this matter. We have done this on a small scale between San Francisco and Oakland and I can see no reason why the system should not be extended to long haul business, providing adequate provision is made for the customary handling of service in case of trouble on the line.

Mr. Dyson has questioned the ability of the subscribers to call, with any degree of accuracy, eight digits, which with the advent of the automatic private exchange into a hundred thousand line system, is sometimes necessary. This is true to a certain extent. If the eight digits represented the number of some single unit, it would be difficult to remember the number while calling. The eight digits, however, represent a composite number of three parts and for this reason is somewhat less difficult to remember. For example, consider a call from one private exchange station to another. The first digit called would be 0, this is to establish the trunk connection, and is not difficult to remember. The next five digits would represent the number of the called exchange as a whole. The remaining two digits would represent the number of the proper local in that exchange. There is no question but that the remembering of numbers is an important point in any system, and one which cannot be overlooked when an attempt is made to eliminate irregularities in operation, and it is well known that many wrong numbers are given by subscribers who attempt to call by memory even when the numbers are short. The addition of a small writing pad to each telephone, upon which the number to be called may be written, would, I believe, be of value in many cases. The calling of wrong locals in an automatic private exchange, apart from disturbing the called party, does not place any great burden upon the calling party. The system as now aranged, permits a second local to be called when the party first called hangs up. The calling party is not required to disconnect.

A valuable feature of the automatic switchboard, which, I believe, has not yet been brought out, is its ability to establish simultaneously, as many connections as its facilities will accommodate. In watching the operation of one of the larger switchboards, I noticed at one time, four mechanical operators start at almost identically the same time. There could not have been a difference of more than a second between the starting time of all four switches. In a corresponding but manually operated

system, at least eight or ten seconds would have to have been devoted to each call, with the result that all except the first station would be subjected to a delay.

Mr. Pope made the remark that most people do not know whom to call when information is wanted and a private exchange is involved in the connection. This, I believe, is largely due to the fact that the present method of directory listing does not give any information as to the different departments maintained by a company. Mr. Pope stated that a great many calls are received by him which should have been directed to someone else. Had the particular department with which connection was desired, been listed in the directory, I have no doubt Mr. Pope would have been saved the annoyance of answering many misdirected calls.

The successful operation of an automatic switchboard depends to some extent, upon its location. For use in the larger cities, it is safe to figure upon boards of all sizes from 10 stations up. Very small exchanges can be economically handled when two or more of them are in the same building, which permits the use of a common switchboard.

Arthur Bessey Smith: (Communicated after adjournment): Mr. Deakin's paper is full of interesting and valuable matter, which will bear an extended and careful study. I wish especially to call attention to one feature of private branch exchange operation to which he has given some attention. It is the matter of indirect calling, which has been the cause of considerable annoyance to telephone users.

The subscriber who is otherwise obliged to work his way through the offices of two or three, or perhaps four, operators, cannot be censured for desiring to throw the responsibility and labor of his work on to someone else, and naturally the private branch exchange operator in his own building is the one selected. The busy man feels the interruption to his work. However, when he is able, by the mere turning of a dial, to place his call directly, the interruption is far less than to send it indirectly through the private branch exchange operator. The evil of the indirect call is sufficiently great to have received the attention of the general public. Sometime ago the writer saw, in a paper devoted to humorous articles the proposal to organize a mutual protective league of telephone subscribers for the purpose of eliminating this evil by refusing to answer the telephone unless the calling party were actually present on the line.

Now the writer does not seriously advocate any such system as this, but we feel that the dictates of common courtesy should lead the telephone user, especially one who uses the automatic system, to make his calls directly, so as to be present on the line when the desired party answers. Since to call on the automatic is so relatively easy, the automatic system should at least be given the credit of being a force which makes for politeness and mutual regard.

Discussion on "The Design of Telephone Pole Lines for Conditions West of the Rocky Mountains" (Griswold) Portland, Ore., April 17, 1912. (See Proceedings for May, 1912.)

(Subject to final revision for the Transactions.)

H. Y. Hall: I ask Mr. Griswold what has been the experience of the telephone companies in the use of concrete particularly, and what has been the effect of the use of concrete on the butt rot. That is, under the weather conditions, applied under similar conditions that exist in the west, and also in the different soils. The paper states " It is the practice to allow the pole to reach approximately a safety factor of one before replacing." Would that apply to all the poles in the line, or to just an occasional pole? I take it that would be rather unsafe to apply a factor of one to a whole line of poles; you might to an occasional pole.

Gerald Deakin: Is the moisture content considered in determining the strength of poles when set? It is well known that the presence of moisture in timber weakens it, and for this reason, the strength of well-seasoned poles, as determined by the tests to which Mr. Griswold refers, would not give the actual strength of the poles when set in moist earth.

W. D. A. Peaslee: There was in the Sierras in 1908, a pole with two crossarms, eight wires on each crossarm, on which the snow and sleet had drifted until the accumulated weight of snow on that pole was forty-eight hundred pounds outside of the weight of the wires. The Southern Pacific at that time ran two copper lines over the Sierras and uniformly along that line from about Blue Canyon down to Truckee, the wire was found next summer, to be much smaller in area. The construction crew went over the line this next summer taking up this slack and practically a uniform decrease in size of about one gage number was found.

The Chairman: Why wouldn't it have been a good idea to leave it?

W. D. A. Peaslee: Because the next summer it would stretch another gage number and would be gone. They have one thing that comes in the Tahoe district along the Tahoe part of the line, that I have not seen or heard of in any other place. There is a green scale forms on the copper wire in the course of two summers. When that was scrubbed off to get down to the copper, it was found one gage less in thickness. I have never heard of it in any other place and I would like to ask if anybody has.

D. P. Fullerton: Referring to the statement made by the previous speaker, I will say that the copper wires of the telephone company which are strung between Truckee and Lake Tahoe, have shown the same condition, in that a green scale accumulates on the wires and apparently causes a reduction in the size of the wire. Nowhere else, so far as I know have our wires been so affected. The lines crossing the Sierra Nevada mountains between Sacramento and Reno and which connect

with the lines between Tahoe and Truckee at the latter place, and go through the same character of country do not show this peculiar condition, although the lines are all exposed to the same general local conditions. No special investigation has been made to determine the source of this scale on account of the fact that the lines affected are rather unimportant circuits and only in use a portion of the year. We do find, however, that all copper lines strung through the Sierra Nevada mountains cause more or less trouble in the shape of shrinkage in the size of the wire and apparent loss of life of the copper due to extremely heavy snow falls that are encountered each year. We do not have the large number of wire breaks that would seem possible at first thought. The principal trouble is the weight of the snow which bears upon the crossarms and carries them from the poles; this being due principally to the heavy crust forming on the snow which settles on the arms as the snow melts underneath.

After a couple of years' study we have found that the life of copper wires, particularly the smaller gage wires, is apparently gone. Considerable study is being made of this, as stated in Mr. Griswold's paper. I will state that these lines were originally built with very little regard to engineering, but we are now giving these questions considerably more study and believe that a great many of our difficulties have been overcome.

P. M. Downing: Mr. Hall has brought up one question which I wanted to ask, *i. e.*, with reference to the life of the pole when set in concrete. There seems to be considerable difference of opinion as to whether or not the life is prolonged by the use of a reinforcing material of this kind. Of late we have all seen a great deal of literature describing different methods of preventing the decay of poles by placing concrete shells around them.

I understand that patents have been issued covering at least two different processes of this kind but so far as I can learn the only essential difference between them is in the kind of reinforcing metal used and the manner of placing the concrete.

I have heard it claimed that a pole would rot only at or near the surface of the ground and not near the bottom of the pole where the air was excluded. On this assumption it has been claimed that it was unnecessary to cover the entire butt of the pole with concrete but that a section for perhaps eighteen inches or two feet below the ground level was all the protection needed. My experience has been that in some localities or some kinds of soil a pole will rot near the surface of the ground and not at the bottom of the pole, while in others the rotting will start at the butt end and work up.

There seems also to be a question as to when it is best to put on this concrete shell. One advocate recommends concreting when the pole is set regardless of whether it is thoroughly seasoned or not. Another recommends that the pole be allowed to stand a few years until it has become thoroughly seasoned

or, even until, at least, a portion of the sap wood has rotted before concreting.

In California we have a great deal of trouble getting seasoned poles. Most of the poles used come from Oregon, Washington and Idaho and when received are either filled with sap or are water logged to such an extent that it is inadvisable to attempt to treat them with any preservative.

I would like to ask the author of the paper whether or not he has ever had any experience along these lines and, if so, what the result has been.

S. J. Lisberger: I ask Mr. Griswold if the telephone companies have used any poles coated with creosote, and if a particular class of soil has any effect upon a creosoted pole. I also ask if any copper clad wire has been used and what the condition of this wire is in comparison with the ordinary copper or iron wires used in that territory?

D. P. Fullerton: There is one point possibly Mr. Griswold may overlook and that is bearing on Mr. Downing's questions, that I would like to mention. In his paper he refers to "peat" fires in the vicinity of Little River in the San Joaquin valley, California. We were troubled there with the poles being burned off below the ground line, and with no sign whatever above the ground line that there was any trouble, consequently, with a long and heavy line, we experienced quite a little trouble. I simply mention this to say that in making some experiments in replacing these poles, we enclosed them with a cement jacket, probably a half an inch in diameter, allowing the concrete covering to extend six or eight inches above the ground line. After the poles had been in place about two years, upon investigation and inspection we found that while this treatment had prevented the burning off of the poles by subsequent fires, and the concrete shell was intact the rot increased at a greater rate than on unprotected poles that had been placed in the same locality a great many years ago.

A. H. Griswold: Answering Mr. Hall's question, our experience has shown that it is not good practise to concrete the butts of untreated poles. We have not had any experience with treated poles, but on untreated poles set in this manner butt rot may take place very rapidly, and on one particular lead of poles in the San Joaquin Valley, as indicated by Mr. Fullerton, the life of the poles was decreased between 50 per cent and 75 per cent.

The use of reinforcing concrete collars to which Mr. Downing refers is open to the same objection of butt rot as outlined above, and in addition may be mechanically weak and very costly.

Replying to Mr. Hall's question concerning the safety factor of one that is applied to each pole: the replacement inspection is made on each pole and the lead is not considered as a whole, but each pole is taken as a unit of that lead.

A safety factor below one is sometimes allowed. This safety

factor takes into consideration the wind velocity and ice load wherever it may occur. In allowing a lead to fall below the safety factor of one you are simply taking a chance that the maximum wind or ice load will not occur before the final replacement of the pole.

In the same connection Mr. Deakin asked whether the moisture content was taken in consideration in the replacement inspection of the poles. I understand that it is indirectly taken into consideration in compiling the replacement tables.

Answering Mr. Lisberger, there isn't any doubt but that the class of soil affects the butt rot of poles.

DISCUSSION ON "PLANT EFFICIENCY—AN ANALYSIS OF THE LOSSES OF A HYDROELECTRIC SYSTEM" (ROSS), PORTLAND, ORE., APRIL 18, 1912. (SEE PROCEEDINGS FOR MAY, 1912.)

(Subject to final revision for the Transactions.)

Gano Dunn: It is startling indeed to see the resulting efficiencies so carefully and accurately computed as have been computed in this paper, and it is also startling to see a considerable difference in the amount of this total efficiency from what probably it would have been given in the prospectus of a hydroelectric company had this company been in the course of financing instead of in actual operation. In one table there are given certain efficiencies of impulse units and certain turbine units, and both seem considerably low. If I understand Mr. Ross' use of the figures right, these statistics indicate lower than full load efficiencies. Am I right, Mr. Ross?

J. D. Ross: Yes, sir. The full load efficiencies are given in the curves, Figs. 2 and 3.

Gano Dunn: Of course in a station where there are few units, it is difficult, if not impossible to run the units at full load. In taking the Institute's honorary member, Dr. C. E. L. Brown, of Switzerland, who rushed through the Pacific Coast a few weeks ago, through the waterside station of the Edison Company in New York, Mr. Lieb remarked it was one of the strictest rules of the company never to run the machines except at full load, and that, therefore, they never cared what the efficiency of the plant was, and the average load under which the stations had been running in the past was about 101½ per cent. If that is so, why is it not possible to insist in the operation of our systems more upon full load, running units with a vew of improving the relatively low efficiency shown by Mr. Ross' calculations. I know the human element is against it, but it needs only for us to be shown what the total diminution is in a case like this for us to be stimulated, and to do as much as we can to correct it by seeing that the best efficiencies are employed in the apparatus we use. We run a generator or a wheel under a full load, and when the load varies, add units instead of changing the load as a whole. This practise of calculating the accumulation of little quantities is an old but fundamental principle. The differences made by a lot of little things always astonish people that compute them. I think we ought to call Mr. Ross the Benjamin Franklin of the present era because he puts into electrical terms the maxim "Take care of the pennies and the dollars will take care of themselves."

S. J. Lisberger: Mr. Ross has now presented us with a valuable paper. I think he has done himself a slight injustice, however, in considering the subject of station lighting or substation lighting as losses to the system. I believe if Mr. Ross had to go before his own board and ask it for more money or possibly an increase in the rate, he would be told he might well justify an increase in rate, or he might justify a demand that he

be allowed a certain amount of money for lighting the stations. I don't know how much that will help his losses. I think it has been the rule of most state commissions that the companies are allowed for their own business the actual cost of production of that current as a charge against the particular department in which the current is used. Mr. Ross has stated that the economic size of his alternating feeder is 350,000 cir. mils. That seems at first glance rather an excessive size of copper. As a matter of fact, I don't recall any systems that use that size. I ask him what is the approximate or average distance from the center of distribution to the stations, and at what rate or what value he figures lost current. That will have much to do with the economic size of the feeder in question. I also ask him, in figuring the kilowatt-hour output or kilowatt-hours stolen from the customers' meters, what method he used in making these estimates.

R. Howes: The waterwheel in a hydroelectric plant is at the fountain head, so to speak, as its efficiency affects the entire available output I would like to ask if there was any specific reason why the turbines should give such a continuously rising efficiency curve. The gates are of a wing type, if I remember correctly, so it would be interesting to know why these wheels were not designed to have maximum efficiency at something less than the full load.

J. B. Fisken: It seems to me that the curves should show the maximum efficiency at about 100 per cent load with a drooping characteristic on either side; the efficiency also seems low. The 100 per cent load shows a turbine efficiency of about 75 per cent. I would like to know whether Mr. Ross can say if that should not be 10 per cent higher? We have no trouble at all in our wheels in getting 86 or 87 per cent and on some of the new wheels we have ordered, we are guaranteed almost ninety per cent. I agree with Mr. Lisberger in regard to the charging of the station lighting. It seems to me that should be charged as an expense and not as a loss, and not against the efficiency of the plant. There might also be a slight saving, I cannot say how much, by the use of three-phase transformers instead of single-phase transformers.

L. F. Harza: I ask Mr. Ross if the 5,000-kw. load is the rated load on the generator? I also ask if a test on the full gate power of the unit was ever made to determine how many kilowatts could be developed? I have found in a number of instances that water wheels are too large for the generators, and in one instance, a 2500-kw. generator has been operating with water wheels so large that at the 2500-kw. normal load on the generator, the wheels operate at, as I recall, somewhere about 70 per cent. The wheels are, however, capable of developing better than 80 per cent efficiency but only at a high overload of the generators, the fault being entirely due to too large capacity of the water wheels rather than inefficiency. The result is that in order for the unit to run at normal generator rating, the wheels must operate at low gate opening and hence low efficiency.

There has been a very common trouble in the office where I have been employed in recent years in buying waterwheels, small enough. On one contract we had to reject successively two wheels which were built and tested at Holyoke before we could get the manufacturers to build one of as small a capacity as we wanted. The trouble was, I believe, that we specified that the units must be capable of developing *at least* a certain horse power under a given head, which is a very common specification, and one which we found it necessary to discard on this account. We found that the water wheel builders design the wheels for a greater capacity in order to meet their power guarantee and apparently cannot predetermine the maximum capacity of their wheels accurately enough to work to that specification without the danger of getting the wheels too large for the generators. I will show some curves in discussing Mr. Coldwell's paper later on, which will illustrate the point more clearly.

O. B. Coldwell: I have been very much impressed with Mr. Ross' paper, from the short acquaintance I have had with it. I have long been an advocate of attempting to find out what things do in actual practice where they are installed as against what they might do on the floor of the factory in being tested or at some other point where conditions are not exactly the same as they may be after being installed. Mr. Ross' paper has stated just such an actual condition as that, and I consider it of much more value than a paper dealing merely with the test results not attached to practise. In the company which I represent we have during the past few years been heading in the same direction. We have attempted to test in place, water wheels, generators, transmission lines and all other parts of the system. To date, we have not put this all together and assembled it as Mr. Ross has been able to do. In the waterwheel tests which we have made, we have employed very largely the Pitot tubes, conditions being such as to make the weir measurements impracticable, at any rate, it would have been a very difficult matter to have used a weir. We have, in addition to water power plants, the steam plants entering into our system as relays, and if we were to attempt to talk about the total efficiency we would have that factor entering in. Again it so happens, we have two frequencies of generation, 33 cycles which is the hold-over from early practise, and a lot of apparatus of that type, and it is still doing plenty of good work and cannot be dispensed with, and in addition the sixty cycle; and as we have transmission lines of 33 and 60 cycles working together as a unit more or less, our problem of working out plant efficiency would be more complicated perhaps. I notice in looking over Mr. Ross' paper, that the average losses for the year are the ones shown as the basis of this discussion. I might state that the operating records which we are using in connection with the Portland Railway Light & Power Company are made up entirely by readings taken from watt-hour meters which are read once every hour. While we have many indicating instruments all over the

system no records are kept of them. The watt-hour meters are read once every hour and plotted on a cross section sheet by the attendant with colors used to show the various types of service, and there is thereby on record for the station attendant's benefit, as well as that of the operating department later, on an exact picture of what is going on in the station. A number of companies on the coast have load dispatchers' systems and have found them of great advantage. I might say that we are just at the present time installing a system of that sort wherein we will put the question of deciding just how many units are to carry the load, etc., to an expert, rather than leaving it more or less, as it has been done in the past, to the discretion of the operators. Mr. Ross mentions the benefit which may be derived by properly educating the operator in the use of his apparatus. I want to say we have found this particular class of record which we have been keeping—that is the drawing of a picture, as it were, of the operation of the station from day to day—to be of very great benefit to the operators themselves.

H. Y. Hall: In reference to the point raised by our chairman as to the operation of units at the most efficient point. I do not think that the operator of the hydroelectric plants is to blame for a unit not being operated at its most efficient point, so far as conditions are in the west, at different hydroelectric plants. Of course, in the case of the New York Edison plant, they have stations with over a dozen units of different sizes and their load is not so very variable, so they can operate at the most efficient point. With a hydroelectric plant the conditions are entirely different. A great many plants are one-unit plants, some two, but very rarely over four units; then the point may be raised as to why put in a lot of units so as to operate that at the most efficient point under all load conditions. The question of the load factor comes into consideration, and the cost per unit and the full-load efficiency due to the small units. It seems to me that the criterion isn't so much efficiency. It seems to me that we harp too much on the efficiency and we pay for that efficiency at times when it isn't really worth what we pay. After all, the criterion is what it will cost us, everything considered, to turn out so many kilowatt-hours at such and such load under such and such conditions. With a plant that has no storage capacity the light load efficiencies don't cut any figure. It is the full load efficiency that is the important point.

J. B. Fisken: I ask Mr. Ross if any Pitot tube measurements were made to check the constants of the weir measurement, and if they were, how many traverses were made with each measurement.

Mr. Ross: Mr. Chairman, in answer to Mr. Lisberger that the station lighting losses should not be charged up against the losses of the system, I really believe he is right, for two reasons. One reason is that a good deal of that lighting is for advertising purposes and we are increasing it now on the line of the Milwaukee Railway Company, where we are going to put in a little

advertising. I suppose this really should be charged to advertising, the same as printing would be. The station lights inside the building, itself, used for the operators should be classed a little different it is true, but still, perhaps, should be charged up, aside from the losses, as a commercial load. The object of this test, though, was not altogether for the paper; in fact, the test has been going on several years. What we wanted was a full test of our plant. Now, Mr. Hall, said that the full-load efficiency was the only thing we can consider in any diversion system. That is practically true. As I said at the outset, this paper is for a storage system, and the distribution end of it is also largely applicable to a steam plant. Where you have a purely diversion system and do not store your water then, of course, the principal thing is to run your machines at full load. To obtain the maximum efficiency, is the important thing. Mr. Hall, also, has stated that too much stress was put on efficiency, and I surely agree with him there. The idea of this test was to raise the efficiency wherever possible, provided this could be done without extra cost, and you will notice there are a lot of little places where that can be done. The question of regulation is very important. You know the man that comes in and kicks usually is not kicking so much on his bill as he is on his regulation, and if there is a lack of efficiency, it can be made up in higher prices a good deal easier than a lack of service can. Of course, where we are, the lack of service sends a man to the other company—some of you are familiar with that, and some not; we always find it is a good thing for the operator, it keeps him alive. I don't believe efficiency is the whole thing by any means. On our secondary, we figure on two volts, maximum voltage drop; after we get over two volts we try to get busy. Of course, we miss it in a good many cases, but that is our rule.

Mr. Hall has spoken of the rising characteristics of these particular turbines. These turbines were built, the first ones manufactured in this country for a six hundred foot head. Now that is a rather delicate question to answer. I never like to answer anything where the manufacturer is concerned, because when we have a difference with a manufacturer, we generally like to settle it with him and after this settlement everything is all right. The makers built an 8600-h.p.wheel. We would like to find a rising curve to full load, and then a falling off, and we have now actually arranged for another pattern of runner. I think, myself, they got the runner a little wrong in the diameter. I am not a waterwheel man. My figures may be entirely wrong. I wouldn't uphold them against those of the designer of a waterwheel, but I think there is a little mistake in the runner, although the wheel is an excellent wheel and the relief valve made by the same people is also doing excellent work.

As to tests, Mr. Fisken or Mr. Harza asks if a full load, full-gate test, had ever been made. At the time the test was made, we ran up to about 5000 kw. on the generator, or about 6600 horse power. In order to get the proper load, we put on rheostats, we

took a piece of six-foot stave pipe and put a bottom on it, and placed resistance coils in water in it. We connected the generator to this resistance and took our readings using that load, but the wheel was not up to full-gate opening. We also handled that test a good deal like a farmer handles a basket of eggs for the reason that to follow the test too far might mean a shut down for the service. We liked the operation and the regulation of these two turbines very well and at the same time I do believe that a mixture of Peltons and turbines would give a better and quicker response to change of load.

Mr. Coldwell asks whether the Pitot tubes are a success; he says they are attempting to use them and asks if we are trying them. I would like to know Mr. Coldwell's results on the Pitot tube; I would like to see them and compare them with current meter readings, and see the results obtained. We tried the Pitot tube and it may be we did not get the right kind. We made them up, the University tried them, and we tried them, made according to what is supposed to be the best practise, but we failed to have them check with the weir and current meter readings. We took about three hundred current meter readings in our tail race and also measured the water over the weir. Our load in that test was constant because we put the rheostat on, we kept our power factor constant on the machine and any excess load we carried on another machine. As to the accuracy of the curve, I don't think there is any doubt. We ran complete tests on that curve twice.

We expected about eighty-three per cent efficiency from the turbines, and the contract was so drawn up that any drop in efficiency below that made a forfeiture of a certain amount. The makers were businesslike in the whole thing, and being one of their first machines—the very first one of that head—I think they made a little error in the runner, but we are going to get a new runner with a maximum efficiency at the point we want. I think Mr. Harza asks if 5,000 kw. was the normal load of the machine. The guarantee of the manufacturers was 5,000 kw. at 40 deg. rise and 4000 kw. at 35 deg., and the machine met the guarantee. Our two Peltons are connected to a different make of generators and they are rated on the same basis of 1500 kw., 40 deg. rise, but we run them right along at 1750 kw.

As to the water wheels being large in comparison with the generators, I believe that Mr. Harza is right; we ought to have a wheel fitted for the generator it drives. We have merely accepted the wheels subject to the conditions and specifications which were freely met; and the makers offer to furnish a new runner to give us the efficiency desired at any particular place.

As to the economic size of wire for 200-ampere feeders 300,000 circular mils may be a little large, but if you take into account voltage regulation, it is better to be above than below the right s ze, and we believe 300,000 circular mils is about the proper size. For down-town business there is no question about it, because regulation is so important.

A paper to be presented at the 276th Meeting of the American Institute of Electrical Engineers, New York, October 11, 1912.

(Subject to final revision for the Transactions)

THE USE OF REACTANCE IN TRANSFORMERS

BY W. S. MOODY

Until recently, reactance in transformers was considered only as an objectionable characteristic. To this there was one minor exception, which will be referred to later on, in connection with transformers to furnish constant current for arc lighting; but in general, because of its detrimental effect on regulation, reactance in transformers has been considered something to be avoided, and the more it was avoided the better was the transformer supposed to be fitted to its use.

Recently, however, in connection with the use of larger units in generating stations, and higher voltages in transmission lines, reactance in other parts of electrical installations has become less and less, until a short circuit in such a system may result in such a tremendous flow of current, that some means of limiting the possible current rush through the system has become imperative. The most natural remedy is to replace in the system, by the transformer, some of the reactance that has been taken out.

Reactance has commonly been used as a means of obtaining a variable ratio of transformation between the source of supply and the collector rings of synchronous converters, but when more than 3 or 4 per cent reactance is desired for this purpose, it has been customary to use separate reactance coils between the transformers and the converter. A very satisfactory method of obtaining as high as 15 to 20 per cent reactance for this purpose in the transformer itself, has been recently developed.

It is the object of this paper to discuss in a general way how reactance can be introduced into transformers for the purposes mentioned above, to point out some of the difficulties and limitations which are met in obtaining the desired results, and to show

how effectively some of the problems connected therewith have been solved.

As all know, a transformer would have no reactance when under load if all the lines of force created by its primary threaded through the secondary and if all the lines linking the secondary also linked the primary. Such a complete interlocking of the primary and secondary fluxes is, of course, impossible, a portion of the fluxes always passing through the spaces between the primary and secondary coils.

The percentage of the total flux that links with the primary but does not link with the secondary coil, plus that which links with the secondary but does not link with the primary, is the per cent of reactance of the transformer. That is, when 99 per cent of the primary flux cuts both primary and secondary, the transformer is said to have 1 per cent reactance, and when 90 per cent, only, cuts both primary and secondary, it has 10 per cent reactance.

Calculations for reactance are made by an equation of the form,

Reactance Volts =

$$\frac{(\text{Turns})^2 \times \text{Current} \times \text{Area of leakage path}}{\text{Length of leakage path} \times (\text{No. of groups})^2} \times \text{a constant} \quad (1)$$

From this formula, it is evident that reactance for a given size of transformer may be decreased,

a. By decreasing the total number of turns in primary and secondary.

b. By decreasing the length of turn, with a corresponding increase in the flux density in the core, or by decreasing the distance between primary and secondary windings.

c. By increasing the dimensions of the windings in the direction in which the leakage flux passes through the wire space.

d. By increasing the number of groups of intermixed primaries and secondaries, the number of turns in each group being correspondingly reduced.

So much effort has been put forth in designing transformers of the lowest possible reactance consistent with reasonable expense in the matter of insulation and efficient proportioning of the various parts, that one would naturally think that if low reactance was not desired, it would be a much easier problem to make a transformer.

Several difficulties are met, however, in the design of trans-

formers with high reactance, principal among which are an extra loss in the conductors due to eddy currents, an increase in mechanical strains under overloads, and difficulties in multipling different sections of the windings. Some of the leakage flux between the primary and secondary windings must pass through the conductors of the windings themselves, resulting in an inequality of the e.m.fs. generated in different parts of the same conductor. This gives a distorted distribution of current, producing a copper loss, in addition to the calculated I^2R loss, which is roughly proportional to the square of the density of the leakage flux, and to the square of the width of the conductor in a direction at right angles to the leakage field. Unless the width of the conductors is small, therefore, high densities of leakage flux are not permissible, on account of the resulting abnormal copper loss, and the corresponding increase in heating, and decrease in efficiency.

Perhaps the first use of high reactance in transformers was that referred to above, to obtain in the secondary, constant current rather than constant potential for purposes of arc lighting. Here, however, not a constant reactance but a variable one was needed. High reactance was here obtained without high densities in the leakage flux, by providing a large cross sectional area of the leakage field rather than many turns; and since the conductors were not large, no especial difficulty was experienced with eddy currents. The increased reactance for partial load conditions in these transformers is obtained, by moving the primary farther and farther away from the secondary, so that the leakage flux is increased by increasing the area of cross section of its field, the density remaining constant.

This method of obtaining high reactance is very expensive because of the great length of core that is necessary to surround this idle space, in addition to surrounding the copper and insulation and is prohibitive in large units. The reactance that can be obtained economically, without a density of leakage flux which is not too high from the standpoint of eddy current loss, varies with the voltage of the transformer, for the higher the voltage the greater the distance that must necessarily exist between primary and secondary windings for insulation purposes, and therefore the greater the amount of flux that can be carried through this space without serious eddies in the copper. Thus it may be as easy to make a transformer with 10 per cent reactance when wound for 100,000 volts as for 5 per cent reactance when wound for

25,000 volts, due to the broader path that exists for the reactive flux in the high voltage design.

As a general proposition, it may be said that it is usually impractical to get more than 8 per cent reactance in 60-cycle transformers without undue eddy current losses, and that the allowable maximum would be considerably less than this in low-voltage designs. For lower frequency, higher reactance may be practical, since eddy current losses are, of course, less at a given density.

It has recently become customary to specify that the transformer must not have less than, say 5 per cent reactance, for the protection of transformers, switches, generators, and in fact all parts of the system against the high mechanical stresses due to excessive currents. It is not always, appreciated, however, that limiting the current in this way, while protecting other apparatus, does not necessarily make the transformer any safer to withstand overload conditions.

Calculations for the mechanical stresses in the transformer may be made by the equation,
Mechanical stress =

$$\frac{(\text{Turns})^2 \times (\text{Current})^2}{(\text{Length of leakage path})^2 \times (\text{Number of groups})^2} \times \text{a constant} \quad (2)$$

where the groups are all alike; or where the groups are not alike,
Mechanical stress =

$$\frac{(\text{Turns})^2 \times (\text{Currents})^2}{(\text{Length of leakage path})^2} \times \text{a constant} \quad (3)$$

where the turns considered are not the total of the transformer, but the turns in that group which has the maximum number.

From the above equations, it may be seen that when high reactance is obtained by massing the turns in a small number of groups, the "turns" factor of the expression for mechanical stress is increased, though the "current" factor at short circuit is reduced. If the groups are not kept equal to each other, the maximum stress, which occurs in the maximum group, and which produces the forces that are felt by the core and coil supports, is likely to be actually greater under short circuit conditions for a high reactance transformer than for a low reactance one.

With equal numbers of turns in all the groups, the forces will be greater for the low reactance transformer than for the high

reactance one at absolute short circuit with full voltage maintained on the primary terminals, although not enough greater to make a very serious difference in any case where the supports are designed to supply a proper factor of safety for the high reactance transformer. Moreover, with a definite fixed current flowing, the force will be much smaller for the low reactance transformer than for the high reactance one, and with a comparatively small external impedance, in addition to the impedance of the transformer, the force due to short circuit becomes less for the low reactance transformer than for the high reactance one.

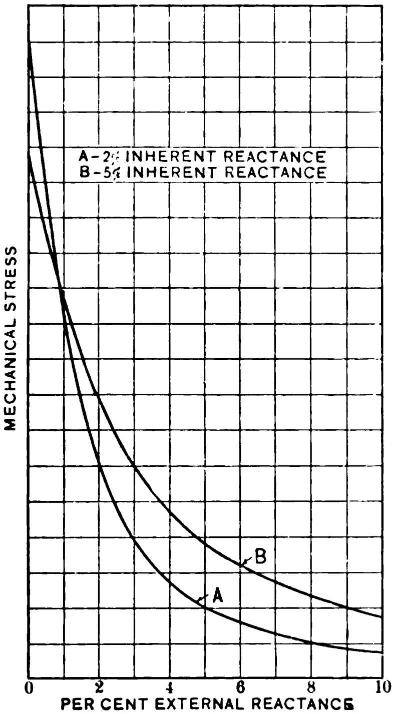


Fig. 1.—Effect of External Reactance on Mechanical Forces in Transformers

From the above it will be seen that very little is to be gained from the standpoint of safety to the transformer by the introduction of high reactance within the transformer itself. It is true that this would protect other parts of the system, but the additional reactance would be equally as effective for this purpose outside of the transformer as inside of it.

This is illustrated by Fig. 1, which shows the mechanical stresses under short circuit conditions, in a transformer designed for 2 per cent reactance and in the same transformer when redesigned for 5 per cent reactance. It is assumed that constant voltage is maintained at the primary terminals. With normal current only flowing, the mechanical stresses in the high reactance design are higher than in the low reactance design, but when short circuit occurs at the secondary terminals, the stress is higher in the low reactance design. This is shown on the curve for zero external reactance. With the addition of about 1 per cent external reactance, the curves cross and with further increase in external reactance, the high re-

actance transformer is subjected to the greatest strains. With 3 per cent external reactance added to the low reactance design and none to the high reactance design, thus making the total in both cases 5 per cent, the stress in the former is only about one-fourth as great as that in the latter.

When short circuit occurs at some distance from the transformer, the reactance of the lines adds to the transformer reactance and serves to reduce the stresses on the transformer. In fact, in this case the line resistance also assists, and a smaller value of external reactance will cause the two curves to cross and the stresses in the low reactance design to become less than those in the high reactance design.

The effort to obtain sufficient reactance for current limiting purposes in an auto-transformer is a more difficult problem. These are frequently used for a one-to-two ratio of transformation, as, for instance, in stepping-up the voltage of a 10,000-volt generator to 20,000 volts. Here the auto-transformer has only half the rating of the generator, and the effect of its reactance on the system is only one-half that of its own inherent reactance. In some cases where it is necessary to get the equipment in the smallest possible space or keep to the lowest possible costs, it is necessary to be satisfied with what current-limiting reactance can be placed in the system by such an auto-transformer, but an exceedingly rigid design of coil supports then becomes necessary.

When greater amounts of reactance are desired for flexibility in ratio of transformation, as for use with synchronous converters, the result can be obtained by placing a laminated iron structure between primary and secondary in such a way as to form a path for the leakage flux. If this iron path is of such a section as to carry the flux corresponding to the desired reactance without approaching saturation, the copper will be entirely shielded from eddy currents, and the transformer's reactance may be increased almost without limit. It is evident, however, that the use of such a device does not extend the possibility of current-limiting reactance, as the amount of iron that would be necessary to carry the entire flux on short circuit would result in a prohibitive amount of reactance, from a regulation standpoint, at normal loads.

It is interesting to note that this use of an iron path for the reactive flux, as well as the high reactance design in which the flux is entirely within the air space between primary and second-

ary, was first developed in connection with arc lighting apparatus, where transformers with a fixed high reactance were used to obtain regulation characteristics approaching constant current. The proportioning of these flux shunts for transformers with

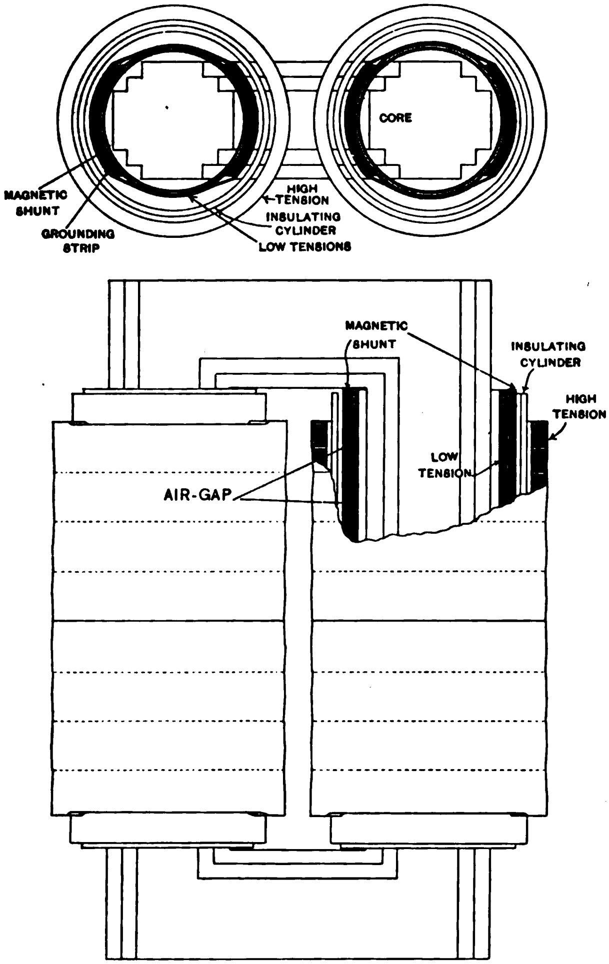


FIG. 2.—DIAGRAM OF CORE TYPE HIGH-RESISTANCE TRANSFORMER

regulating reactance is an interesting and not altogether easy problem, and it may be of sufficient interest, in view of the fact that it has been so recently reduced to practice, to be worthy of comment here.

Evidently there must be as many shunts as there are spaces between primary and secondary groups. Evidently, also, the section of these shunts must bear the same relation to the section of the core of the transformer as the reactance voltage bears to the full voltage of the transformer. This on the assumption that the density in the shunt at full load is to be the same as the normal density in the core at normal voltage. However, it is usually the case that if a straight line characteristic is to be obtained in the reactance, say, up to 50 per cent overload, the section of each of these shunts must be somewhat larger than this;

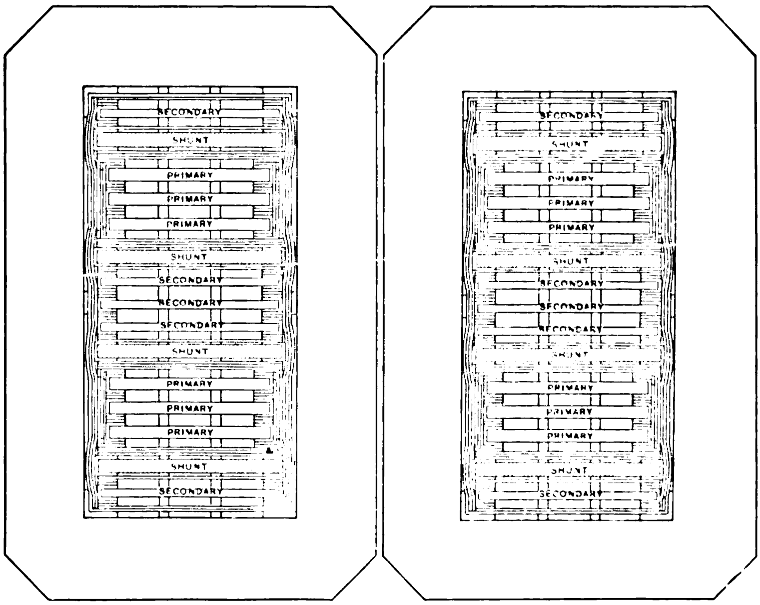


FIG. 3.—DIAGRAM OF SHELL TYPE HIGH-RESISTANCE TRANSFORMER

that is, for 15 per cent reactance the section of the shunt will have to be perhaps 20 per cent of the section of the transformer core.

Again, it is necessary to have air gaps in this circuit: First, because a straight line characteristic can not be obtained with any, magnetic circuit that is a closed iron circuit; and second, because in any group of ampere turns that would be practical, a sufficient magnetomotive force would be obtained to oversaturate the shunt circuit at full load if there were only the reluctance of the iron circuit to limit the flux. It should be noted

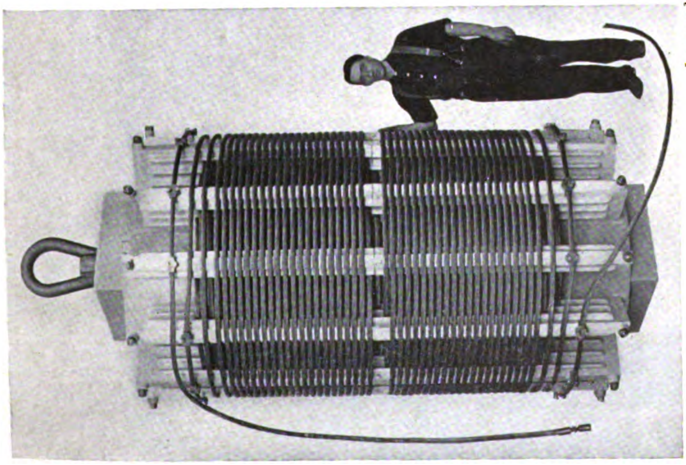


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FIG. 4.—LARGE CONCRETE CORE CURRENT-LIMITING REACTANCE

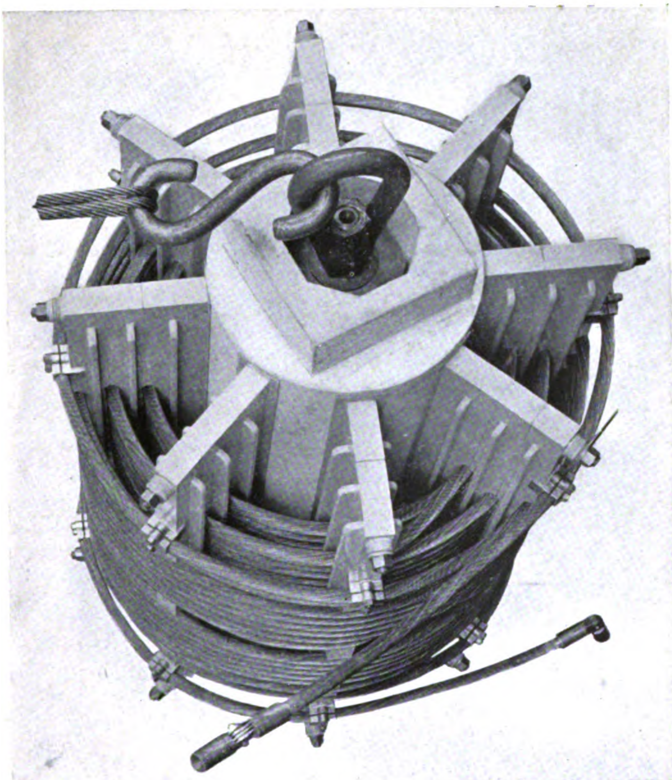

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FIG. 5.—CURRENT-LIMITING REACTANCE SHOWING ARRANGEMENT OF CORE, SUPPORTS AND WINDING

that the loss in these shunts is not a constant one like core loss, but varies with the load; consequently, it affects efficiency as if it were a copper loss. However, the loss in the shunts is small as their weight is very small compared with the weight of the core.

Figs. 2 and 3 illustrate the manner in which these flux shunts are placed in core type and shell type designs, respectively.

Figs. 4 and 5 show the general appearance of the concrete core external reactances which have been developed and successfully used in large power systems to limit the flow of current at short circuit.

A paper presented at the Urbana Section meeting of the American Institute of Electrical Engineers, Urbana, Ill., Feb. 21, 1912.

(Subject to final revision for the Transactions).

PROPERTIES OF THE WEHNELT CATHODE RAYS

BY C. T. KNIPP

The discharge of electricity through gases is a subject that has had a most wonderful growth,—a growth possibly greater than that of any other single division in physics. With the discovery of cathode rays, X-rays, radio-activity, and rays of positive electricity, a new era was begun. The cathode rays were the first of the above to be brought to our attention, however, but little was known of their properties until the researches of the last decade. About fifteen years ago the wonderful X- or Roentgen rays were discovered. A few years later came that almost revolutionizing discovery of radio-activity,—revolutionizing because we are obliged to change our conceptions regarding the molecule and atom. Another of equal importance because of its bearing upon chemical composition, is afforded by J. J. Thomson's recent investigations on rays of positive electricity.

These avenues in physical science that have been opened by the researches of such eminent physicists as Crookes, Roentgen, Thomson, Rutherford, the Curies, Wehnelt and others, have played, and will play a most important part on the problems of the consititution of matter and the nature of electricity. It is safe to say that we know more nearly what is going on when electricity passes through a gas than when it passes through either liquids or solids.

Let us take, for instance, an ordinary discharge tube (exhibiting tube) connected to a quick acting pump (*e.g.*, the Gaede). First notice the form of the tube and its construction. This one is 1.5 meters long, and about four cm. in diameter. The two electrodes are flat disks of aluminum about two cm. in diameter

and placed one at either end. The connection to the pump is at the center.

In operating this tube it is necessary, as stated above, to have some means of exhausting it. This may be done by any one of a number of pumps that are on the market. A time honored method is to use a Geissler mercury pump. To cause a current to flow through the tube a suitable source of high potential must be available, such as an electrostatic machine or an induction coil. We have here an induction coil (exhibiting coil) that will give a spark of 10 or 15 cm. The ease with which the current passes through the tube depends upon the amount of air in the tube, *i.e.*, upon the pressure. When the pressure is 76 cm. of mercury (atmospheric) the discharge passes with great difficulty, requiring several thousand volts per centimeter, but as the pressure is reduced by pumping, the current passes more readily, and soon a stage is reached where the resistance offered by the gas in the tube is a minimum. In order to study the discharge critically it must take place in but one direction—it must be unidirectional. The current from the induction coil may readily be made so by introducing a gap in the circuit. The current may be reversed by a commutator. Notice that no discharge takes place on closing the circuit of the induction coil when the pressure is atmospheric. We will now start the pump. Its action is rapid and in a few moments the pressure will be reduced sufficiently to allow the discharge to pass. Notice how stringy it is. By means of the parallel spark gap at the induction coil, we see that this 1.5 meters of tube corresponds to about 3 cm. of air at atmospheric pressure. Notice that it is becoming more fuzzy—that it is spreading out and filling the tube. On reversing the direction, we notice but little difference between the ends. Note the color. Also note that the parallel gap must now be very much reduced to cause it to spark there. The tube now is completely filled with the discharge, and this is the stage where the resistance offered by the remaining gas is a minimum. The parallel gap now must be very short to allow a spark to pass there. This stage is known as the Geissler tube stage, and the pressure is 1/300 or 1/400 of the original pressure in the tube, (*i.e.*, two or three mm. of mercury). We notice now a marked difference in the appearance of the two ends of our discharge tube. On reversing the current the illumination at the ends interchanges. Obviously then, since our current is unidirectional, the effect within the tube where

the current enters is different from that where it leaves. The electrode where it enters is called the anode, while that where the current leaves is the cathode. If we are to examine our current as to its direction, we would find that the luminous end is the anode and the other the cathode. On close examination we see that the cathode is covered with a velvety glow. Just beyond is a dark space known as Crooke's dark space. Immediately beyond this is a luminous part called the negative glow, while beyond is another dark space called Faraday's dark space. The luminous region extending from this to the anode is called the positive column. Notice the alternate dark and bright spaces in this column. They are called striae. At first they were close together and barely visible, but as the exhaustion is pushed they separate and now are more prominent. Their position and prominence depend on a variety of conditions such as pressure, size of tube, gas in the tube, etc.

As the pressure is reduced the positive column recedes towards the anode. The spark is now passing with more difficulty as may be shown by the parallel spark gap.

We now notice a new phenomenon within our discharge tube. The tube is beginning to glow with a faint greenish phosphorescent light which is rapidly becoming more and more marked. The color of this light depends on the kind of glass used—soda glass producing a greenish and lead glass a bluish phosphorescence. This phosphorescence is due to minute particles shot off normally from the surface of the cathode and impinging on the surface of the glass. These particles travel in straight lines and have a high velocity.

They have many interesting properties. They carry negative charges of electricity, are deflected by either a magnetic or an electrostatic field, have a mass which is roughly 1/1000 that of the hydrogen atom, may ionize a gas through which they pass, *i.e.*, by reason of their high velocity they may break up by collision the molecules of a gas into component positive and negative charges, and lastly these particles possessing large kinetic energy and high velocity are the origin of, or better, the direct cause c the production of the X- or Roentgen rays with which we are now so familiar.

The fact that these rays travel in straight lines enables us by suitable diaphragms to isolate the cathode beam. A tube thus constructed is called a Braun tube. Sometimes the tube is constructed with two parallel plates mounted on the inside

for electrostatic deflection, while the magnetic deflection is produced by bringing the poles of an electromagnet in position from the outisde. The Braun tube at once suggests possibilities of hysteresis measurements, and this has been successfully done by Professor Ryan in the Ryan-Braun tube.

We will now pass to the work on cathode rays by Professor Wehnelt of Berlin. In 1904 he found that the stream of cathodic particles could be very much intensified if an incandescent salt is used for the cathode. In fact he found that he could dispense with the induction coil or Wimshurst machine and connect directly to a storage battery of comparative low voltage. The ease with which these ions escape from the hot lime surface makes it possible for the discharge to pass, provided the conditions of temperature of lime, pressure in tube, etc., are right, at an impressed potential difference of less than 100 volts.

This cathode which bears his name is constructed as follows: A narrow strip of platinum foil, about 1.5 mm. wide, is mounted between the ends of the two leading-in wires. On the center of this strip is placed a minute quantity of, say calcium chloride, or indeed a touch of high grade sealing wax will answer seemingly equally well.

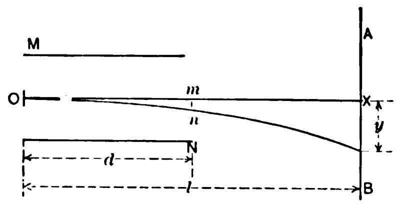


FIG. 1

In operating, the platinum strip is gradually heated to incandescence, while the positive terminal of our storage battery is put in contact with the anode and the negative terminal to the hot lime. When the conditions within the tube are right a sharply outlined beam will issue normally from the surface of the hot lime and travel the full length of the tube, provided, as stated above, the pressure is low enough. In case the pressure is too high the beam will be diffused and absorbed by the remaining gas in the tube.

For certain purposes this beam of Wehnelt cathodic rays has distinct advantages over the ordinary cathode beam. The ions are moving slower and hence are more readily deflected by either a magnetic or an electrostatic field; the beam starts directly from the source without the use of diaphragms and hence the lime cathode may be placed directly in the fields; and lastly, the discharge is very steady since the current is continuous and not intermittent as in the induction coil. In other respects these rays are the same as the ordinary cathode rays.

Let us now turn to the electrostatic and magnetic deflection of these rays.

First, consider the theory of the electric deflection. Let $O X$, Fig. 1, be the path of the undeflected beam. $M N$ the electric field plates, and $A B$ the screen. Let $Y =$ the electric force, $d =$ the length of the field plates, $l =$ the distance of the screen from the source and y the displacement to be determined.

The equation of motion is

$$m \frac{d^2 y}{d t^2} = Y e$$

where m is the mass of the electron, and e the charge of electricity on it.

Hence

$$\text{Accel.} = \frac{d^2 y}{d t^2} = \frac{Y e}{m} = a$$

The deflection downward at mn is,

$$y_{mn} = \tfrac{1}{2} a t^2 = \tfrac{1}{2} \frac{Y e}{m} t^2 = \tfrac{1}{2} \frac{Y e}{m} \frac{d^2}{v^2}$$

and the velocity downward,

$$v_{mn} = \frac{Ye}{m} t = \frac{Y e}{m} \frac{d}{v}$$

Now the additional deflection downward in going from m to the screen $A B$ is,

$$y'_{mn} = \frac{Y e}{m} \frac{d}{v} \left(\frac{l - d}{v}\right)$$

Hence whole distance downward is,

$$y = \tfrac{1}{2} \frac{Y e}{m} \frac{d^2}{v^2} + \frac{Y e}{m} \frac{d}{v} \left(\frac{l - d}{v}\right)$$

$$= \frac{Y e}{m v^2} d \left(\frac{d}{2} + l - d\right)$$

$$= \frac{Y e}{m v^2} d \left(l - \frac{d}{2}\right)$$

which may be written

$$y = \frac{A e}{m v^2} \qquad (1)$$

where A is a constant depending upon the electrostatic field and the geometrical data of the discharge tube. We see that the electric deflection is inversely proportional to the energy of the particle, *i.e.*, inversely proportional to mv^2. This is always true.

We will now turn to the magnetic deflection. We will place the electromagnet so that its lines are coterminous with the electrostatic lines. Then from our knowledge of the behavior of a moving charge in a magnetic field the deflection will be at right angles to the plane of the board—*i.e.*, at right angles to the electrostatic deflection. The case is similar to the electrostatic one, and in order to get the z displacement it is only necessary to substitute for $\frac{Ye}{m}$ the value $\frac{Hev}{m}$, where H is the magnetic force, and e, v and m are the same as before.

Making this substitution we get,

$$z = \frac{He}{mv} d \left(l - \frac{d}{2}\right)$$

If the magnetic field is not coterminous with the electric field, then we must prime d and l, thus,

$$z = \frac{He}{mv} d' \left(l' - \frac{d'}{2}\right)$$

In either case we may write,

$$z = \frac{Be}{mv} \tag{2}$$

where B is a constant depending upon the magnetic field strength and the geometrical data of the discharge tube. Again notice that the magnetic deflection is inversely proportional to the momentum, *i.e.*, inversely proportional to mv.

The above method is based upon the supposition that the fields (both electric and magnetic) end abruptly at the edge of their respective plates. This as we well know, is not the case. A discussion of the necessary correction in the electrostatic case is too long to enter upon here. Under certain conditions the error is not appreciable—those conditions are that l be large in comparison to d, and also to the distance apart of the electric field plates.

However in the magnetic case it is appreciable and I will outline a method recently devised by Professor J. J. Thomson that

is free from error. Figure 2 is looking down from above and along the lines of force. Thomson places a triangular coil, of length l and width at base d, with the base resting on the screen $A\,B$. This coil is wound with a layer of very fine wire, and is connected to some flux measuring instrument such as a Grassot flux meter.

The formula that applies is,

$$z = \frac{e}{m\,v}\,\frac{I\,l}{n\,d} = \frac{B\,e}{m\,v} \tag{2}$$

where I is the total flux through the coil as indicated by the fluxmeter, l the length of the triangular coil, d the width at the base, and n the number of turns.

We thus have in equations (**1**) and (**2**) the electric and magnetic deflections respectively. It is clear that if we apply the two fields simultaneously the spot on our screen will not be along either the y or z axis, but at some intermediate position, P. Obviously then we can calculate, by combining equations (**1**) and (**2**), either the velocity v of the electron, or the ratio of the charge on the electron to the mass of the same, e/m. Solving for v between the two equations we have,

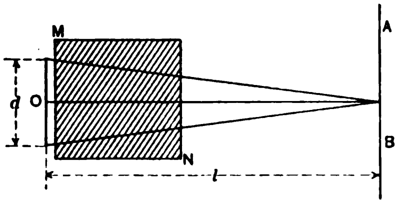


FIG. 2

$$v = \frac{A\,e}{m\,v\,y} = \frac{B\,e}{m\,z}$$

from which

$$v = \frac{A}{B}\,\frac{z}{y} = C_1\,\frac{z}{y} \tag{3}$$

and

$$\frac{e}{m} = \frac{z\,v}{B} = \frac{A}{B^2}\,\frac{z^2}{y} = C_2\,\frac{z^2}{y} \tag{4}$$

where y is the electric and z the magnetic displacements respectively.

We have before us the apparatus intended to show these deflections. The electrostatic plates may be seen within, and by their position the electric deflection will be vertical, as will be shown by the spot moving vertically when the electric field is turned on. Reversing the direction of the field reverses the direction of the deflection.

The magnetic field is furnished by this vertical two-part solenoid. As previously stated the deflection of the spot due to the magnetic field will be at right angles to the magnetic lines of force. Turning on the field we get a deflection to the right, then to the left when the field is reversed.

By turning on the two fields simultaneously, we get a resultant displacement, say, in the first quadrant. We may readily change this to any other quadrant by the proper directions of the fields. The magnitude of the deflections, both electric and magnetic, may be readily adjusted to any value.

It is interesting in this connection to give the results of a calculation made from data taken with this apparatus. The numerical values of the constants are, $A = 70 \times 10^{10}$, $B = 4.6 \times 10^2$; and the deflections were adjusted to, $y = 4.8$ cm., $z = 4.8$ cm.
From which $v = 1.6 \times 10^9$, and $e/m = 1.5 \times 10^7$.
These values compare very favorably with the values obtained by numerous investigators for the case of the ordinary cathode rays. For the latter we have $v = 2.6 \times 10^9$, and $e/m = 1.7 \times 10^7$.

This experiment suggests several possible practical applications. The system is sensitive and responds readily to slight variations in the respective fields, but it is doubtful, because of the difficulty in heating the lime cathode, whether its practicability will ever extend beyond the research laboratory.

We saw in equation (**2**) that a magnetic field deflects the cathode particle at right angles to the direction of the field. The question naturally arises, what will be the path of the ion if the magnetic field is indefinitely increased? The simplest case is when the field is at right angles to the path of the ions. The velocity of the ion remains constant. It has been shown that the normal force towards the center $= Hev$. This must be equal to the centrifugal force of the moving ion acting outward along the radius of curvature. This from dynamics, is

$$\frac{m\,v^2}{\rho}$$

where ρ is the radius of curvature.

These two forces must be equal, hence,

$$H e v = \frac{m\,v^2}{\rho}$$

or
$$\rho = \frac{m\,v}{H\,e} = \text{radius of circle.}$$

Suppose that our magnetic field

$$H = 50 \text{ gausses}$$

and
$$v = 10^9 \text{ cm.-sec.}$$

also
$$e/m = 1.7 \times 10^7.$$

Then
$$\rho = \frac{m\,v}{H\,e} = \frac{10^9}{50 \times 1.7 \times 10^7} = \frac{100}{85} = 1.2 \text{ cm.}$$

Hence for a field of 50 lines per square centimeter we should expect the ion to travel in a circle of approximately 2.5 cm. diameter.

We have an apparatus[1] designed especially to show this circular path. Its distinctive feature is the mounting of the Wehnelt cathode. (See foot note for reference giving full description).

In operating an apparatus like this, it is more convenient to change the order of manipulation; that is, to place the cathode so that the cathode beam passes parallel to the axis of the glass cylinder—parallel to the magnetic lines of force—and later turn the cathode until the emerging beam takes up a position at right angles to the lines of force. If the vacuum is high enough the beam should reach to the millemite screen, and if it is truly parallel to the lines of force, it will suffer no deviation. The millemite screen lights up. Now we will turn on the magnetic field. The beam is but little affected. Next turn the cathode slightly. Notice the form that the beam assumes—a long graceful spiral. Further turning brings the spiral into greater prominence—winds it up as it were. It is interesting at this point to note the effect of varying the magnetic field. Again leaving the magnetic field constant let us vary the current by changing the temperature of the hot platinum. These effects are very marked and are in full accord with theory. Turning the cathode still farther increases the pitch of the helix when finally it degrades (theoretically) into a circle.

An ion, then, shot at random across a magnetic field, will, in obedience to the forces acting upon it, move in a spiral. If the field is uniform the path described is a helix. The tendency is for an ion to move along the lines of magnetic force. That this is the case was seen in the experiment just described. Yet

1. C. T. Knipp, *Phys. Rev.*,. Vol. 34, Jan. 1912.

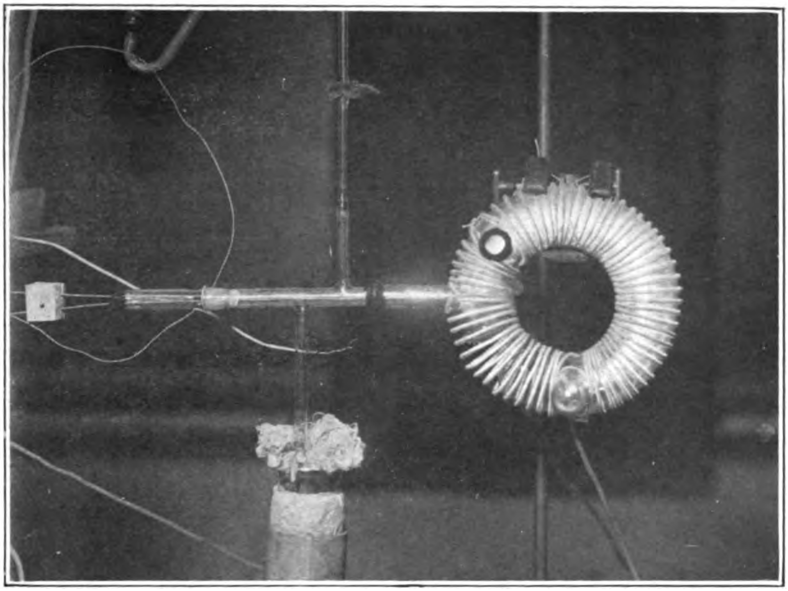
a further experiment is necessary to thoroughly convince us of this statement.

Fig. 3 shows a discharge tube of unusual form—circular but not reentrant. The magnetizing field coil, in the form of a toroid so as to secure a uniform circular field within, is of heavy wire and of few turns. The tube is thus plainly visible. It has affixed to it one of the specially mounted Wehnelt cathodes.

To begin with, we will set the cathode so that the emerging beam lies in the plane of the coil when no field is on. You can plainly see the beam strike the glass a few centimeters above the cathode. In this position it is tangential to the axis of the discharge tube. If now, as we saw by the previous experiment, the ions *tend* to follow the lines of force, the beam should, when a strong magnetic field is turned on, follow the axis of the discharge tube in the form of a spiral. And so it does. In fact, the beam as far as we can judge by the eye, follows the axis exactly as is shown by the photograph of the discharge reproduced in Fig. 3. This, however, is not in accord with theory. The form, no doubt, is a spiral of long pitch and very short radius, and thus its form as such is not detected by the eye. It is clearly seen to be a spiral when weaker magnetic fields are employed. The question naturally suggests itself, will the beam, (or better, the resulting spiral) still follow the axis of the tube when the cathode is turned through an angle? On turning the cathode we find that in this case, too, the axis is followed. The inference at once is that the helix as a whole does follow the lines of magnetic force, while the ions only *tend* to follow them.

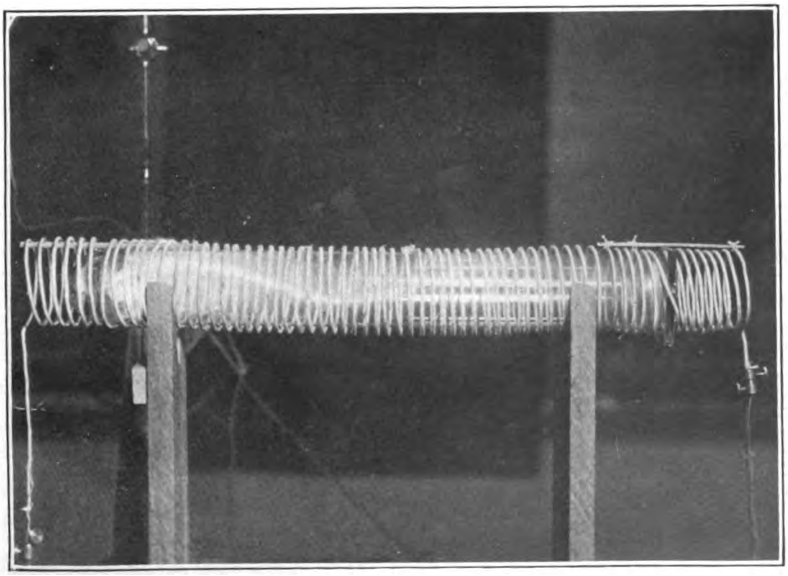
For some months past we have been trying to realize a compact yet long helical beam of cathode rays for purposes of electrical measurements, believing that such a beam under proper conditions would form a very sensitive indicator. The sprial experiment described above was the first step in the realization of such a beam. We shall present now the beam as we have perfected it to date. The apparatus, Fig. 4, is simple, even more so than those that were just used.

It consists of a large tube, about 6 cm. in diameter, and about 60 cm. long. One end is closed round, while the other is cut off square and closed by a plate of heavy glass on which is spread a willemite screen. A nipple is fused in near the round end and through this is inserted the specially mounted Wehnelt cathode —it being free to turn at right angles to the axis of the discharge tube. A transparent (loosely wound) solenoid is slipped over



[KNIPP]

FIG. 3



[KNIPP]

FIG. 4

the tube. This solenoid is carried a few turns beyond either end in order to secure a uniform field the full length of the tube.

We will begin by sending the discharge along the axis of the tube. The beam may not be overly sharp. Turning on the magnetic field changes its position but little, but has the effect of making it compact and thus bringing it into prominence the full length of the discharge tube. The beam, however, is not uniform. It has the form of a ribbon twisted several complete turns, the latter depending upon the strength of the magnetic field. This sharpening of the beam is nicely shown on the willemite screen. On turning the cathode, the beam first takes the form of a long graceful helix (Fig. 4) which increases in pitch as the turning is continued. The winding up as it were of the helix is beautifully shown by the end view on the willemite screen. On close examination it is seen that the cross section of the helix as pictured by the screen is very clear cut. Turning our attention again to the helix, we see that it is deflected by an outside magnetic field, even though this field is much weaker than that within the solenoid. With the other conditions remaining constant we again notice the effect on the diameter of the helix by varying the potential difference impressed on the discharge tube. Again as before, keeping the discharge constant, we note the effect of varying the temperature of the Wehnelt cathode. Lastly if we swing the central part of the coil back and forth the helix within keeps apparently in perfect step, *i.e.*, compressing the solenoid increases the magnetic field, which in turn increases the pitch of the helix.

Your attention was called a moment ago to the realization of a long helical beam and to the statement that such a beam under proper conditions forms a sensitive indicator. The possible application is in determining the nature and constitution of light. Professor J. J. Thomson has, from theoretical considerations, come to the conclusion that ordinary light may not necessarily consist of a smooth wave motion through the ether but that it may consist of pulses,—in short, may consist of positively and negatively charged ions. It seems barely possible that the question may be tested experimentally by some such helix as we have been studying. The theory underlying the experiment is that if a beam of light were concentrated on a helix near its source the picture on the willemite screen would show blurred if the light consists of positively and negatively charged ions, but would not be affected if light is an undulatory motion

through the ether. Why the image in the former case would be blurred is not difficult to explain. The cathode beam consists of negatively charged ions. If these are hit by both negatively and positively charged ions some will be deflected in one direction and others in another, the sum total effect being a blurring of the image on the screen.

Whether Professor Thomson's view is correct, time only can tell; nor is the failure of an experiment like the one described conclusive evidence against the theory, for it will require refinements in methods and manipulation that far exceed the comparatively crude results that we have described in this paper.

A paper to be presented at the 276th Meeting of the American Institute of Electrical Engineers, New York, October 11, 1912.

(Subject to final revision for the Transactions.)

THE EFFECT OF TEMPERATURE UPON THE HYSTERESIS LOSS IN SHEET STEEL

BY MALCOLM MACLAREN

In the paper which the writer presented before the Institute last year upon this subject* it was shown that there was no apparent change in the law governing the variation of the hysteresis loss with the induction for all temperatures from atmospheric up to near the point where the steel became non-magnetic. The writer suggested at that time that the rate of heating the sample might affect the change in hysteresis loss with changing temperature and the measurements described below were carried out to investigate this point. It was thought also that some additional light might be thrown on this subject if hysteresis loops were obtained from the sample near the non-magnetic temperature. This had not been done in the previous tests as the samples had been prepared for the two-frequency method of measurement in order to obtain results quickly at any temperature over as wide a range of induction as possible. An attempt was made at that time to obtain a few characteristic loops at high temperatures, but the use of iron wire for the secondary winding on the sample introduced errors on account of variable thermal currents in the galvanometer circuit which could not be readily eliminated. It was also found that the insulation resistance between primary and secondary at high temperatures was not sufficiently good to permit measurements by the galvanometer method, although no error could be detected from this source with the two-frequency wattmeter method.

*Proceedings: A. I. E. E. Vol. XXX., April, 1911, p. 537.

Method of Measurement

In the present investigations the measurements were made by the method of slow reversals as described in the previous paper. The arrangement of connections for the test is shown in Fig. 1. The hysteresis loop is obtained by first applying a magnetizing force H to the sample by passing a current through the primary winding. It is advisable to reverse this current several times before taking the observations in order to make sure that the induction in the sample is in a stable condition. The galvanometer switch should be open during these reversals. The galvanometer is then connected across the secondary winding and by inserting resistance in the primary circuit the magnetizing force is reduced at such a rate as to keep a constant deflection on the galvanometer. At the end of 10 seconds, or any convenient time interval, the ammeter reading and galvanometer deflection are recorded. At this point the galvanometer deflection may be altered and then held at a constant value for 10 seconds when the ammeter and galvanometer readings are again noted. This process is continued until the current is reduced to zero, reversed and gradually increased until it reaches the same value as at the beginning of the test. The galvanometer readings then give a complete record of the change of induction for a complete reversal of the magnetizing force and the ammeter readings give the corresponding values for the magnetizing force. In C. G. S. units the change in induction B during any interval is obtained from the following expression:

$$B = \frac{K \, \delta \, t \, 10^{-8}}{S \times A}$$

where k = galvanometer constant
δ = galvanometer deflection
t = time interval (10 seconds)
S = number of secondary turns

$$\text{also } H = \frac{2 \, T \, i}{10 \, r},$$

where A = area of cross-section of sample in square centimeters
T = number of primary turns
i = amperes in prinary winding
r = mean radius of sample.

The maximum value of B for any reversal may be found from the following expression:

$$B_{max} = \frac{k\,\Delta\,t\,10^{-8}}{2\,S \times A}$$

where Δ is the sum of the deflections for a complete reversal.

It should be noted that one reversal of a current gives one-half of the hysteresis loop. If the observations are accurate this is sufficient as the other half is symmetrical with it. In all of these measurements, however, except at the maximum temperatures, the observations were carried through the entire cycle or double reversal, in order to check the accuracy of the results.

It was found in practise that it was not always possible to keep the galvanometer deflection constant between readings and in such cases the average deflection was noted. The

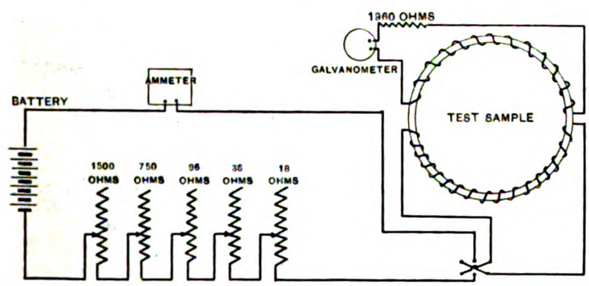


FIG. 1

time required for going through the cycle was minimized without loss in accuracy by using larger deflections in the middle of a reversal than were permissible at the beginning and end.

Test Samples. Two samples were tested, they each consisted of a number of sheet steel rings. The inside diameter was 25.4 cm. and mean diameter 26.66 cm. Sample 1 consisted of a commercial steel used for pole punchings. The average thickness of the sheets was .693 mm. Sample 2 consisted of high silicon transformer steel, the average thickness of plate being 0.348 mm. Sample 1 had a primary winding of 160 turns of No. 18 iron wire and a secondary of 50 turns of No. 20 copper wire. The cross-section was 6.165 square cm. and the weight 3.989 kg. Sample 2 had a primary winding of 168 turns and a secondary of 50 turns, both of the same wire as before. The

cross-section was 6.585 square cm. and the weight was 3.989 kg. In each case the rings were separated at the center by U-shaped spacing strips to allow the introduction of thermo-couples. The secondary was first wound on the sample and was insulated from it by sheet asbestos and mica. It was then covered with a thin layer of Portland cement, and a second layer of asbestos and mica. The primary was then wound over this and distributed as uniformly as possible around the ring. As the secondary covered only about $\frac{1}{4}$ of the ring, the inside surface of the remainder was padded with asbestos to the same thickness as the secondary in order to assist in obtaining an even spacing of the primary turns. The whole sample was then covered with a second layer of Portland cement. The use of copper wire for the secondary absolutely eliminated the thermal e.m.f. which had

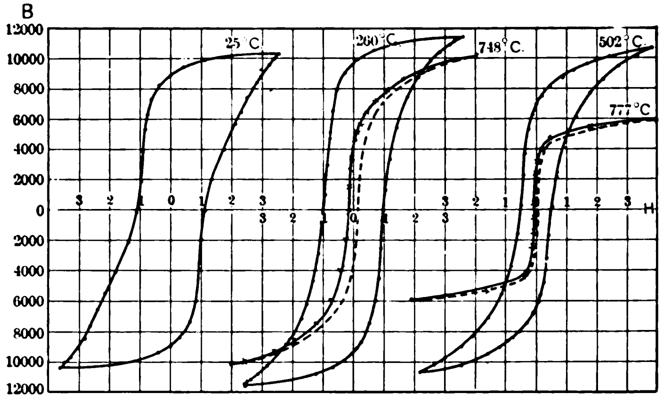


FIG. 2

been present in the earlier samples. As anticipated, however, it did prove to be durable for such high temperature work. After one heating oxidation increased the resistance about 25 per cent and the wire became so brittle that on one sample the terminal broke off upon removing it from the furnace. The change in resistance introduced no error in the observations as the resistance at start was only 0.3 ohm, and total resistance of the galvanometer circuit was 2450 ohms.

The insulation resistance between primary and secondary was about 200 megohms when cold and fell to less than one megohm at the maximum temperature. At these extreme temperatures it was possible to detect a mere trace of leakage from primary to secondary, but this only occurred with high

values of exciting current and was so small as to introduce no appreciable error on the results.

Electric Furnace. The same furnace was used as in the earlier experiments. This consisted of concentric heating coils arranged to give us as uniform a temperature as possible in the heating chamber. The temperature was measured by platinum-iridium thermo-couples, introduced into the sample through small holes cut in the walls of the furnace.

Results

Sample No. 1. In this series of measurements the temperature was increased quickly and then held practically constant while a set of observations sufficient for one complete cycle was

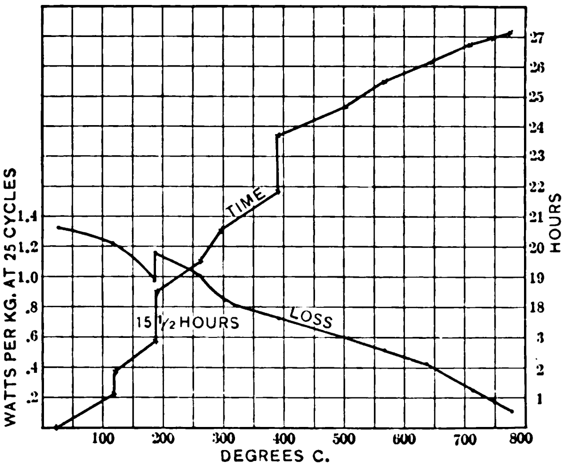


Fig. 3

being made. During the earlier part of the run the temperature was held constant for an hour or more and then a second set of observations was made. When it was noted, however, that the losses did not change appreciably during such intervals, the later measurements were made without holding the temperature constant longer than was necessary for one set of observations. The effect of aging when a constant high temperature is maintained for a longer period was well illustrated during this run by keeping the sample at about 186 deg. cent. during one night.

Representative hysteresis loops taken during this run are shown in Fig. 2 and the results of the complete series are given in table I. The losses are also plotted with reference to temperature in Fig. 3. These are reduced to a constant induction of

10,000, on the assumption that the loss will vary as the 1.6 power of the induction.

TABLE I

Time	Temperature	Induction	Magnetizing force	Watts per kg at 25 cycles	Watts corrected for 10,000 B
2.45 p.m.	25 deg. cent.	10357 B	3.6 H	1.4	1.33
3.55 "	116 "	10686 "	3.6 "	1.355	1.23
5.40 "	186 "	11506 "	3.6 "	1.225	.98
8.00 "	186 "	11473 "	3.6 "	1.235	.99
9.15 a.m.	186 "	11428 "	3.6 "	1.43	1.16
10.15 "	260 "	11457 "	3.6 "	1.255	1.01
11.20 "	300 "	11379 "	3.6 "	1.037	.841
12.35 p.m.	392 "	10936 "	3.6 "	.85	.738
2.25 "	389 "	10913 "	3.6 "	.851	.738
3.25 "	502 "	10676 "	3.85 "	.662	.598
4.15 "	562 "	11139 "	4.08 "	.613	.517
4.50 "	640 "	10986 "	4.08 "	.489	.421
5.30 "	708 "	10340 "	4.08 "	.268	.252
5.40 "	748 "	10149 "	4.08 "	.1665	.164
5.50 "	777 "	5952 "	4.08 "	.0474	.109

Sample No. 2. The observations were made upon this sample without holding the temperature constant for any extended period, except at noon and the measurements immediately before and after this period were practically the same. Some of the hysteresis loops taken during this test are shown in Fig. 4 and the variation of the loss with the temperature is shown in Fig. 5. The results are given in detail in table II.

TABLE II

Time	Temperature	Induction	Magnetizing force	Watts per kg at 25 cycles	Watts corrected for 9000 B
8.00 a.m.	25 deg. cent.	9787 B	2.52 H	.652	.572
9.50 "	134 "	9270 "	2.52 "	.584	.556
10.40 "	225 "	8820 "	2.52 "	.526	.544
11.35 "	304 "	8719 "	2.77 "	.488	.511
12.20 p.m	408 "	8482 "	2.77 "	.397	.437
2.35 "	395 "	8472 "	2.77 "	.397	.438
3.40 "	542 "	8281 "	3.02 "	.342	.391
4.20 "	610 "	8651 "	3.30 "	.228	.243
5.45 "	725 "	6818 "	3.33 "	.0525	.082
5.55 "	735 "	4387 "	3.5 "	.0185	.058
6.05 "	745 "	1193 "	3.4 "	.00	.00

Comparing the results in the two cases it is seen that there are certain variations in the shape of the loss curves although the general trend is the same. These variations are quite as likely to be a function of the previous heat treatment of the samples as

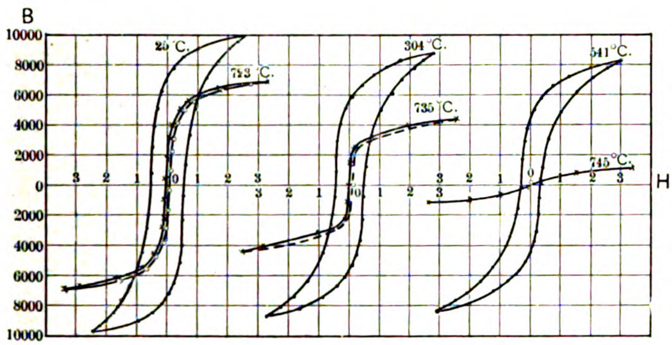


FIG. 4

of their chemical composition. It will be seen that the high silicon steel becomes non-magnetic at a lower temperature than the ordinary steel and also that its permeability falls with increasing temperature throughout the test, while with sample

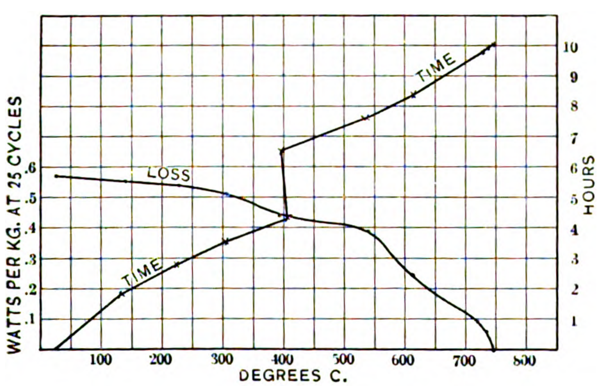


FIG. 5

No. 1 the permeability first rises and then falls away with increasing temperature. No special significance should be attached to this last point, however, as an inspection of the hysteresis loops would indicate that if lower inductions had been used the permeability would have first increased with the temperature

in both cases. Both sets of experiments show that the temperature may be held constant for an hour or more at a time during the run without appreciably changing the hysteresis loss.

Cooling Curves. A series of observations made upon sample No. 1 as it was coming into the magnetic state are shown in Fig. 6. The temperature was falling slowly while these observations were being made and as the permeability varies rapidly with the temperature during this critical period it was apparent that magnetic changes were occurring in the sample while the test was being made, so that the value of B for the maximum H was not the same at the end as at the beginning of the reversal and a true hysteresis loop could not be plotted. An at-

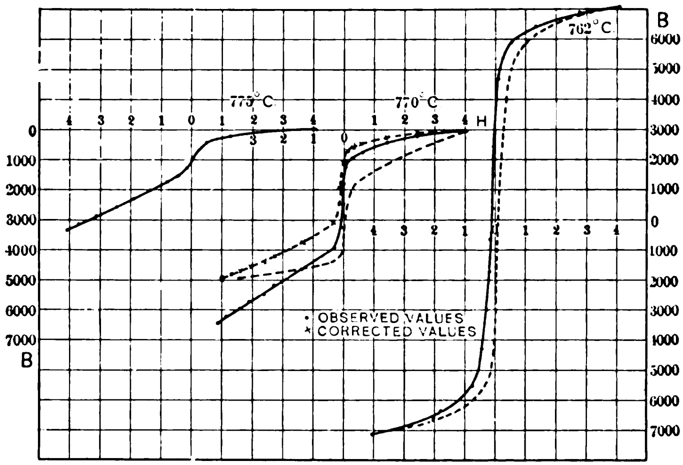


FIG. 6

tempt was made, however, to correct approximately for this in the second set of observations by considering the general shape of the curve, from which it appeared that the induction at start was about 2,500 lines. This would mean that about 1,430 lines were added to the circuit during the observations through change in temperature. Assuming that this change occurred fairly uniformly with the time, each observation may be corrected to show the approximate induction which would have existed with constant temperature by multiplying 1430 by the ratio of the time from the start to the time of the entire reversal and subtracting this from the observed value of B. In this way a complete loop, as shown in broken lines in Fig. 6, was obtained.

Little importance could be attached to a single set of observations corrected in this way except as they are confirmed by tests upon sample No. 2. In this case the temperature fell very slowly and the time required for taking the observations for one reversal was about one minute so that the slight changes occurring in the magnetic state during the reversal could not materially alter the shape of the hysteresis loop. Three such loops are shown in Fig. 7 and it is seen that they have much the same character as the loop shown in Fig. 6. The

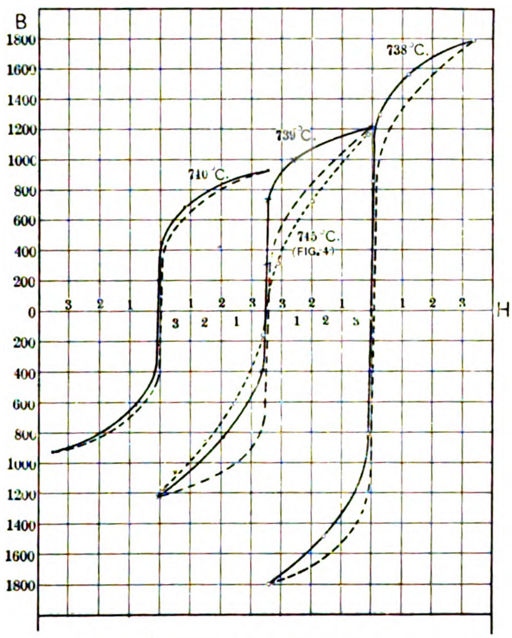


FIG. 7

difference in the character of the reversal during heating and cooling is well illustrated by comparison with the dotted line which reproduces in the proper scale the last reversal with rising temperature as shown in Fig. 5. When the temperature fell to 735 deg. cent. the loops became normal. The writer regrets that he has been unable to make further investigations to verify these observations for if these figures represent true magnetic cycles they show a peculiar molecular condition for the material near the critical temperature.

Critical Temperature. In the earlier experiments with alternating current the temperature at which the material became non-magnetic was quite clearly defined, but in these tests with a sensitive galvanometer it was possible to detect a trace of magnetism in both samples eight or ten degrees above the temperature at which the induction ceased to be measurable. With alternating current it appeared that the material returned to magnetic state at the same temperature as it became non-magnetic, while in these later tests, at the lowest measurable induction the temperature was about 10 deg. lower upon cooling than for the same induction and magnetizing force with rising temperature. Such differences may be due to lack of uniform temperature throughout the sample in every case or possibly the continued application of an alternating magnetizing force may assist the material in regaining its magnetic properties. This point was investigated further with sample No. 2 by maintaining a constant magnetizing current in the primary while the material was passing through the critical temperature during both heating and cooling. As the induction fell through the loss in permeability, an e.m.f. was generated in the secondary which could be observed with the galvanometer. In order to get a measurable deflection under such conditions it was necessary to remove the external resistance from the galvanometer circuit and the leakage between the primary and secondary circuits then caused a deflection of several millimeters in the galvanometer and it was not possible to sharply define the point at which the galvanometer deflection became zero due to the reduction of the permeability of the sample to unity, but with rising temperature, this occurred at approximately 750 deg. cent. and with falling temperature a reversal in the galvanometer deflection, indicating a rising permeability, could first be detected at 740 deg. cent. The maximum deflection corresponding to the point at which the permeability changed most quickly with the temperature occurred at 745 deg. cent. with rising temperature and 715 deg. cent. with falling temperature. This experiment is of further interest in showing a new, though scarcely a commercial, method, of producing an e.m.f. by magnetic induction in which there is no movement of conductors in the magnetic field nor change in magnetizing current. For if a continuous current is maintained in the primary circuit and the temperatures successively raised and lowered through the critical point an alternating e.m.f. will be produced in the secondary.

At temperatures below the critical point the magnetic characteristics during heating and cooling soon coincide. In Fig. 7 it is seen that sample No. 2 has practically the same permeability for rising temperature at 745 deg. cent. as for falling at 739 deg. cent. At 725 deg. cent. no difference in either permeability or character of loop could be detected.

DISCUSSION ON "RELATIVE COSTS AND OPERATING EFFICIENCIES OF POLYPHASE AND SINGLE-PHASE GENERATING AND TRANSMITTING SYSTEMS." (HOBART) BOSTON, MASS., FEBRUARY 21, 1912. (SEE PROCEEDINGS FOR FEBRUARY, 1912.)

(Subject to final revision for the Transactions.)

W. C. Smith: Mr. Hobart has given us some very interesting figures on a phase of the railway problem which has been very little touched upon. I will add a few comments from the transformer standpoint. Let us take first the step-up transformers. We have, as Mr. Hobart has shown, 48,000 kw. to transform. The development of the transformer has kept pace with that of the generator and turbine, so that there would be no difficulty in providing three-phase units to transform the 48,000 kw. in 8,000, 10,000 or 12,000-kw. sizes. These transformers would be water cooled, no doubt, and would cost, as Mr. Hobart has said, about $2.50 per kv-a. We might take 8000 kv-a. for the capacity of each unit, one transformer corresponding to each turbine, so we would have six 8000-kv-a. three-phase units. Now in the single-phase station we should probably not employ over 4,000 to 5,000 kv-a. transformers. It is possible to secure bids today up to 6000 kv-a. but I think we can take 4000 for the units which would be chosen for this case. Since 75 per cent power factor has been set, we would have sixteen 4000-kv-a. units, which would probably also be water cooled. The high-tension side of the transformers would be 35,000-volt on the single-phase system and 30,000-volt on the three-phase, as Mr. Hobart has pointed out. He has also mentioned a few places where the single-phase situation has been aided by neglecting certain points. I might state here another point. If we have sixteen 4000-kv-a. units it is going to take a much greater space, and the piping arrangements, etc., will be much more in amount than for the three-phase, and altogether the station would have to be enlarged to some considerable extent over that for three phase. On the other end of the line on the three-phase side, the bulk of the transformers and converters are stated in one amount of $20 per kv-a. Probably the transformers would cost in the neighborhood of $3.25 or $3.50 per kv-a., depending on the size. Would we not need more substations on the d-c. line than on the single-phase line? Not being a railway man, it would appear to me that the single-phase would not need as many substations as the d-c. line. However, assuming the same number of stations, we can state that the units would be three-phase and perhaps air blast, or water cooled, depending on the local conditions; The transformers would to-day probably be called for with inherent reactance to take care of compounding the converters. Up to a few years ago it was necessary to supply external reactances for compounding converters, so that perhaps the cost could be cut down somewhat now, due to the fact that we have our compounding reactance as an inherent part of the transformer.

Going to the single-phase substations, unquestionably these should be without attendants, which means self-cooled units. Self-cooled units within the last few years have been developed so that there would be no trouble in providing transformers of 1500 to 3000 kv-a., and I think we could take about 2000 kv-a. as the size that would be ordered under present conditions. With 64,000 kv-a. to be transformed, we would have 32 units. The cost of these was taken at $4 per kv-a. I at first considered this too high. However, on second thought, considering that the transformers are self-cooled and that it has only been by very recent developments that we have gone up to such sizes, it is probable that $4 as compared with the $2.50 is an approximate figure.

Mr. Hobart pointed out the fact that three-phase units are cheaper than single phase. That may be taken wrongly, and I wish to say that a three-phase unit of the same capacity will cost some 15 per cent more than a single-phase, but three single-phase units having the same aggregate capacity as one three-phase unit will probably cost 10 to 15 per cent more than one three-phase unit. Then there is the question of voltage. On the three-phase and d-c. system, we have 30,000 for the high tension line. The secondary would be in the neighborhood of 800 to 1000, depending on whether the direct-current was 1200 or 1500 volts. On the other hand the single-phase would be 11,000 in all probability. At first thought the 11,000 volt, secondaries would cost more than the 1000-volt, and I believe Mr. Hobart so stated, but I doubt if the cost would be more in the large units that we are considering, like 2000 kv-a., and I believe that the 11,000-volt secondary would be perhaps 3 to 5 per cent cheaper than the lower voltage, due to the very heavy current on such large capacities. I will close with one other comment. The last point brought out in Mr. Hobart's paper refers to the development of the static converter or rectifier. I wish to point out from a transformer standpoint the fact that the employment of static rectifiers would permit the use of 60 cycles, as he has stated, rather than 25 cycles. If this is accomplished, and the rectifier is developed to a stage where it can be used for such work, and 60 cycles is adopted, I wish to point out that the transformers would be some 15 to 20 per cent cheaper than those quoted in the paper, which are 25-cycle transformers. In other words, that change in frequency will allow of 15 to 20 per cent saving in the transformers. This is a considerable item.

C. M. Green: What is the comparative efficiency of the two?

W. C. Smith: Before answering that I would like to get an idea from Mr. Hobart as to my assumption that the three-phase synchronous converter stations would be about the same capacity as the single-phase.

H. M. Hobart: It is my opinion that the greater drop in the line with alternating current owing largely to skin effect in the rails, and the desirability from the operating standpoint, of cutting the line up into sections would make it well to have

numerous substations. I do not see why you should forego that advantage in the number of single-phase substations, even though you have 11,000 volts. The system will comprise a great many route miles and I hardly think it would be expedient for a railway with the *very dense traffic* considered in this paper, not to be able to cut up its line into as small sections as at most ten miles, whatever system is used.

C. M. Green: Do I understand you to mean ten miles from the station or place the station in the middle?

H. M. Hobart: I mean along the line of the railway. I think you would want to divide that up into ten mile stations anyway for a line with such heavy traffic as that with which my paper deals.

W. C. Smith: I mentioned the fact that three-phase transformers would cost less than single-phase transformers of the same aggregate capacity. It is also true that at the present time they would probably be more efficient; so that, choosing arbitrarily the three-phase at 8000 and single phase at 4000 kv-a., the probabilities are that the efficiencies would be about the same in the two systems. I think that would amount to a small consideration.

B. A. Behrend: I have consistently refrained in the past from expressing my personal opinion on the merits or demerits of the single-phase system as such, or of any particular part of the single-phase system, as the generating station, the transformer station, the substations, locomotives, etc. Perhaps few men have been so privileged as myself in obtaining an insight into the operation and also the construction and design, as well as cost and the waste of thought, labor and money expended in single-phase electrification, as I have, but I have resisted the great temptation for the last seven years in particular and for the last twenty years in general, to air my views in public. Mr. Hobart's judicial paper, treating this subject in a manner which takes it out of the range of polemics, allows me to express my opinion without compromising myself or the large manufacturing institutions with which I used to be connected for a great many years.

First allow me to express my entire agreement with Mr. Hobart's results. I believe he has stated these very fairly as to the cost of the generating stations. I believe his statement is not quite correct that units for three-phase current generation of 15,000 or 16,000 kw. at 1500 rev. per min. represent the limit at that particular speed. I myself worked out a year and a half ago a 25,000 kw. unit which, if it should ever be built, I have not the slightest hesitation in saying would be successful, and within the conservative guarantees as to temperature rise which it is now customary to make. I believe Mr. Hobart has given us an excellent summary, and after saying this, allow me to make a few critical remarks.

My criticism first of all is this, that the paper deals with but

one-half of the problem, and unfortunately the least important half. The generating station, electric generators, transformers and the line, to my mind, are a mere bagatelle in comparison with the problem at the other end, the locomotive, etc. The problem of operating your locomotives successfully after you have built them is more important. Mr. Hobart's paper is distinctly analytic and analyzes the problem up to the critical point —the locomotive. The method of analysis is distinctly orthodox. The single-phase system has come into large use. I designed some single-phase generators in 1892, and my master designed some 22 years ago, which are still in operation. Mr. Hobart knows of one large successful single-phase power plant at Frankfort on the Main, built in 1892. We must take a heterodox view if we are to look at the single-phase system from the right angle. We must go back on the rules of standardization of the American Institute of Electrical Engineers. We must forget temperature rises as measured by thermometers. We must forget a great many things about electric generators and motors. Unless we do so, unless we turn heterodox, viewing this whole problem from a practical angle, we cannot understand the single-phase system, why it came and why it has done such wonderful good to the electrical engineering industry. I say we must become heterodox. Why? First take the generators—they are very large. Mr. Hobart is right in regard to his diagram only to some extent. Mr. Hobart shows two machines at 4000 kw. I would substitute one of 8000, which would reduce our cost a little. We should obtain a somewhat greater simplicity, which is quite essential. That is a minor matter, however, and does not enter into our argument, because the cost of the power station would be only 10 per cent greater. We must not figure in hundreds when our investment is in millions, and the money a railroad has to invest in a problem is not measured by the cost of the power house. Let your power house be twice as expensive and it will be still all right, if the operation of the locomotives and everything else were ideal; so I say we must be heterodox. We must size up the whole situation and view it not only as the power station—not important alone—or the locomotives—not important alone—but we must take the whole problem and view it as a unit. If the power house breaks down because the electric generators are not designed properly or because some important things are overlooked, very well, change it, and you may be able to obtain a successful generation of power. Let me assure you that after a great many trials and a great many mistakes one of the large corporations in this country engaged in the manufacturing of machinery, succeeded in making the New Haven road a success. I hold no brief for this company or for the New Haven road, but I do want to reiterate that the success of that single-phase power transmission from Woodlawn to Sandford has been a landmark in the engineering business.

Now the next step in the solution of the problem is how can you simplify it—how can you eliminate sources of trouble. Reliability is the whole thing. This must be capitalized—it should be expressed in figures. You cannot do it, but let me assure you that any experienced banker, in trying to form an opinion as to whether his client's funds should be placed in any enterprise, first of all looks not at the financial standing but at the personnel connected with the enterprise. It is the personnel that counts. In regard to this railroad problem, it is the reliability of your railroad, of your electrification problem, which counts in the end, and that cannot be expressed in figures.

The last pages of the paper touch a question of polemics again, the problem of single-phase railways. As I have said, I hold no brief for single-phase railways. I am expressing my opinion for what it is worth. My opinion is that the single-phase system has a field and that the d-c. system has a field; and I have held that opinion for 20 years. The essential point is that both these systems have a field, and let us acknowledge those fields. Let us have the decency to say that a system is all right under certain conditions, but is all wrong under other conditions. Let us remember that 1500 volts for railway purposes has not been tried out thoroughly. I built a number of those high voltage d-c. systems that operate today, with commutators worn fantastically—but still going and delivering current—and therefore I believe that the development of the two systems will be side by side to some extent. The single-phase system, if all the kinks are taken out, which I hope will happen in the end, will have its place. Whether it was properly applied in the case of the New Haven road I do not know. I would like to ask Mr. Hobart whether he would not be so good as to give us his own personal views of the single-phase system, taking the whole system together, for trunk line electrification? I personally do not believe I shall live to see many trunk lines operated by electricity, because it will take such an enormous amount of money that I fear it will be a long time before the railroads can make the purchasers willing to defray the expense of these electric problems.

H. M. Hobart: I do not see why we should use electricity where steam is better. I think the continuous current system has its field, the single-phase has its field, and steam its field. Electrical transmission is appropriate where you can get a reasonable load factor. Where you cannot, there are other and more simple methods. These other methods may comprise the use of electric motors to drive the axles, and still not be electrical in the sense of transmitting electricity from a stationary generating plant to a moving train. I cannot recommend the continuous current system for all cases. It was in 1910 that I mentioned this in discussing a paper entitled "The Economics of Railway Electrification" read before the Institution of Mechanical Engineers, and which advocated the 1500-volt, continuous-electricity system for a road a hundred miles long,

with one train per hour in each direction, a stop every three miles and a scheduled speed of 33 miles per hour. In my contribution to the discussion I stated that for this road the single phase system would be cheaper than the continuous, and that *steam would be cheaper than either*. I gave quantitative calculations in support of my contention. These will be found on pages 1239 to 1245 of the *Proceedings* of the Institution of Mechanical Engineers (London), for 1910.

C. M. Green: It is my purpose to speak of one very small section of this important subject, which we have before us for discussion, and that is the replacement of the synchronous converter by the mercury arc rectifier. I have had the good fortune for the past six years to be associated with the development of the rectifier for series arc lighting up to 9000 volts, 4 amperes, and on multiple work up to 350 volts, 40 to 50 amperes. The growth of the rectifier has been phenomenal, and I consider the future brighter than the past. The reliability of service is of the first and utmost importance, and the life of rectifier tubes and their service varies all the way from absolutely nothing up to over 14,000 hours, and I should be very much disappointed if in five years from now there will not be some tubes which have run over 25,000 hours, and inside of ten years I predict that we shall have tubes in service over 30,000 hours. Seven years ago tomorrow I had the privilege of running 60 kw. (10,000 volts and 6 amperes load) of electrical energy on a single tube, 25,000 volts alternating current across the anodes of the tube. The load for the tube was very excessive, however it did not give out during the short run. Since that time I have seen very much larger currents rectified with lower voltages. I have seen tests run up as high as 1000 amperes and over 1000 volts, but not at that amperage. Frankly speaking, I expect to see the mercury arc rectifier replacing the synchronous converter for 600 and 1200-volt service for railway and other work. It of course means a considerable amount of development and patience on the part of some of the operating companies in order that this result may be accomplished. You can readily appreciate that experimentally the tests must necessarily be of comparatively short duration for the simple reason that the amount of energy required is large and when consumed on water-barrel or resistance load it runs into dollars with great rapidity so that after comparatively short tests it will be necessary to put the apparatus out into commercial service where some use may be made of the rectified energy. This furthermore has the advantage that under these conditions the rectifier is performing useful work and the expense of operating it is almost forgotten.

A Member: About what power factor would you expect to get with a mercury arc rectifier of large capacity on the alternating current supply?

C. M. Green: I should be very much disappointed if we could not readily obtain on a three-phase supply a power factor of at

least 95 per cent. However, the question of power factor depends very largely upon the transformer design and other constants of the rectifier, wave distortion, etc. On single-phase rectifiers for series arc lighting which requires a certain amount of reactance and resistance or impedance in the circuit for successful operation, 65 per cent is about the highest power factor which is obtainable, or an apparent efficiency of approximately 60 per cent, or an actual efficiency of from 90 to 92 per cent on 50 light sets, and above. The power factor for this apparatus is determined almost entirely by the load which it is required to operate. In other words, the situation is more or less similar to operating an arc lamp from a direct-current multiple circuit, 110 volts at terminals of lamp, about 80 volts at the arc and about 72.6 per cent efficiency. Some designs of series rectifiers give a very bad wave distortion of the primary.

Multiple rectifiers for the charging of storage batteries are also limited in a certain respect with reference to the power factor. In other words, if the apparatus is designed for too high a power factor, as the battery is charged the voltage across the terminals of the battery rises and the current falls off very rapidly; the set drops out and the service is unsatisfactory.

Rectifiers to replace synchronous converters would not, to the best of my knowledge, have any of the above limitations, and I believe apparatus could be designed to give a power factor on the alternating-current side somewhat above 95 per cent.

Dugald C. Jackson: I wish to express the interest and satisfaction which Mr. Hobart's presentation of his subject has given to me. With respect to the conclusions, I imagine that with equally reliable data equally well founded on practise, one could come to conclusions which would vary considerably from his, and yet the final result perhaps would be very little different as between the cost of delivering power at a certain point by three-phase generator with converter stations on the one hand and single-phase generator and transformers on the other hand. But when we look at the problem of electric lighting, or electric transmission of power and its distribution, or the special problem of the electrical utilization of power which comes into the railway problem, we must recognize that the question of delivering the power is not the final criterion. The question of making the power available for its purpose in the most satisfactory manner for the least reasonable expense is the final criterion, and the consequence is that while the old war of the alternating current versus the direct current which was waged with great vigor and some acrimony many years ago in the electric lighting field has recently seemed to break forth again in the electric railway field, that phase of the argument does not fairly represent the question before electrical engineers. The question is what will give us motive power for the railway, industrial power for the factory, or service for the electric light that is needed respectively, in the most satisfactory manner for the most

reasonable expense. It has long since been settled for industrial and electric lighting affairs that the direct current has many advantages and the alternating current also has many advantages—sometimes single-phase and sometimes three-phase; neither can occupy the whole field; and I am thoroughly convinced that the same thing will be worked out for the railways. I have already expressed my opinion on that matter before the Institute, especially at the 1911 convention in the discussion of similar papers.

Mr. Behrend is a pessimist in regard to his age in years; I will admit that he is an old man measured in accomplishments, but I believe he will live to see many trunk roads electrified and I therefore must take a certain amount of opposition to his standpoint. In respect to the accomplishments that have been heretofore brought about by the alternating current in the field of electrical transmission of power I can fully agree with him.

A. E. Kennelly: It is a comfort to find a paper on such a complicated subject as this without having to indulge in speculation as to what may have been in the author's mind. The old controversy of the direct versus the alternating current is still with us, and it will be a sad day when it disappears. I look forward to the continuance of that discussion with ever new delight. This particular paper is only on one aspect of it, but it is a very important and practical aspect; and I think the conclusions which are brought out here are a surprise to a great many. We shall hope that an equally strong paper may be written on the other side and we shall enjoy hearing the contest continued over that; but whatever may be said in regard to the exact figures of three-phase versus single-phase power delivered, whatever may be the exact numerical ratio in a particular case, this at least is evident; that Mr. Hobart's paper is a plea for eliminating the stray power, I mean reactive power. Here are cases where the station applies a certain amount of effective power to a track and to a railroad, but in the one case a very large amount of reactive power is supplied which is not utilized, that is in the single-phase case, whereas in the three-phase case very little stray power is generated; and this paper is really a plea for eliminating the extravagance and the incidental cost of that stray power. The discrepancies between the size of the units two to one, the size of the conductors and the size of the various elements of the conducting system are partly due to the fact that there is spare power, unutilized power, in the single-phase system. It carries around one-third for luck and for reserve, being out of use. Of course that is a certain advantage, but it is expensive in size, first cost, etc., but in addition to that there is a very large amount of power that is not being utilized. If we remember, we are all familiar with the fact that on 80 per cent power factor for every kilowatt you deliver usefully you are also generating three-fourths of a kilowatt that is not being utilized at all, and is simply filling

up the machine and utilizing the plant without being dissipated. Three quarters of a kilowatt goes into the magnetic field of the system, into the motor and other parts of the system, and is stored there for a quarter of a cycle, and then comes back in the generator. It is as though in a large steam engine there were auxiliary elements in the plant that required to be fed with a great deal of steam and its heat was dissipated and it came back again into the engine. Of course the boilers would have to supply the engine and also supply the steam necessary for this circuitous auxiliary power. The single-phasers are supplying not only the effective energy that is being utilized for driving the thrust, but they are also creating a lot of energy that is oscillating to and fro in the circuit; and this paper is an indication of the misfortune and the extravagance of that procedure. At the present time that misfortune lies with us, because we cannot bring our power factors on this kind of motor above 75 per cent, whereas with the aid of the converter and the three-phase apparatus it is possible to run nearly 100 per cent; but if this single-phase motor system should eliminate this extravagant oscillation of power which is not being utilized but acts as storage power for a hundredth part of a second, the greater part of this difference between the apparent cost and the final cost would disappear; and if we do not owe Mr. Hobart a vote of thanks for the masterly way in which he presented this subject, we certainly do owe him a vote of thanks for his dissertation upon low power factor and reactive power.

C. T. Mosman: In reading over Mr. Hobart's paper the principal thing that impressed me was the fact that he appeared to be trying to make the strongest possible case for the single-phase, whereas I had always supposed that his sympathies were the other way. There seemed to be many little items where he might have squeezed the single-phase system a little harder, but he lets it get by. The other point I want to mention is that I have heard several people comment that it would be so much better if he had continued and given us the whole story. There is one point in his paper that seemed to me rather extravagant and that was the figure of $20,000 a mile for line construction, which I understood covered the steel tower transmission line. I cannot say that I have had experience on these things at all, but I should think that $20,000 a mile would come pretty near covering all the construction along the right of way for the delivery of power to the cars. It would seem large enough for that. To me it seems very high for a transmission line. Another point is that 30,000 volts would seem very low in figuring out the amount of copper necessary to transmit the amount of power he is considering. I would like to have him speak a few words as to why 60,000 volts would not be a lot better and there would be saved a good deal of investment. I made just a rough estimate that it was three times too high and that you could build the line for nearer $7,000 a mile; and I was surprised that instead

of getting 18 per cent in favor of the single-phase I got 18.5 per cent so it did not seem to make very much difference and I I was considerably disappointed. Coal at $2 a ton struck me as being very low. I had an idea that coal in this neighborhood would cost between $3 and $3.50 at the fire door and my previous impression was that even near the mouth of the mine you probably could not get coal for much less than $1.50 and perhaps a little more at the furnace door. So I would be very much interested in having Mr. Hobart say where $2 a ton applies for first class coal. Outside of these minor points it seems to me the paper is very well taken and although this part of the discussion as applied to railways generally may be a mere bagatelle, it is the particular bagatelle that Mr. Hobart was after and he seems to have found it.

H. M. Hobart: Mr. Smith was quite right in correcting me and pointing out that there probably would not be much choice between the cost of large transformers whether supplied with 11,000-volt secondaries or with 1000-volt secondaries. High pressure does not always mean greater cost in transformer construction. An exceedingly low pressure transformer in big sizes is one of the most difficult things you can undertake. I probably did not make myself quite clear on pp. 180 and 181 in discussing the static rectifier and the advantage of 60 cycles. The case is not quite as good as it seems at first sight. As has been pointed out, there is a certain power factor loss there and you have to have your windings proportioned more liberally in consequence. Certain subsidiary windings must also be provided. Probably the transformers for static rectifiers at 60 cycles would cost nearly as much as transformers for synchronous converters at 25 cycles. If you could employ 60-cycle synchronous converters you would make a gain, because 60-cycle transformers would be lighter and cheaper, but if you substitute static rectifiers, you would introduce difficulties in power factor which offset part of the gain. But the net advantage in lower first cost and greater efficiency of the substation will nevertheless be very great.

C. M. Green: I doubt if you would go up over 5 per cent. There would still be a little advantage in the 60 cycles.

H. M. Hobart: Coming to Mr. Behrend's remarks, I did not mean to imply that 16,000 kv-a. was an utterly impracticable size for a 1500 rev. per min. 25-cycle, three-phase generator, but I intended rather to state my opinion that in the present state of the art, it would not be the best engineering to employ such generators, as they are in the developmental stage. Consequently I took 8000 kv-a. and 1500 rev. per min. as a conservative upper limit. I wanted to employ six generating sets in the station. I then pointed out that the single-phase machine if it was in one generator, would be equivalent in size to a 16,000 kv-a. three-phase machine. I should not consider it approved engineering, at the present stage

of development to employ 16,000 kv-a. generators for 1500 rev. per min.

B. A. Behrend: There are a number of 15,000-kw. 1500- rev. per min. generators in operation now, and I do not know that it would be impossible to build within reasonable temperature limits 25,000 kw. at this speed.

H. M. Hobart: Nevertheless it is not sound engineering to base comparisons on the very uppermost limits that have ever been employed. I was pleased to have Mr. Behrend refer to the great skill, ingenuity and hard work that has been put into the development of the single phase system. I fully believe that there is a field for single-phase, but that most of the work that has been done has been misapplied effort; well meant but on the wrong track. There is a sort of fatality about the single-phase system. In several of the systems for which it has been put forward, there does not appear to be much of a case for electric transmission to the train. I fully agree with Prof. Jackson that all systems are useful, and it is just exactly that standpoint which I felt ought to be upheld as distinguished from staking everything on one system, whether single-phase, three-phase, or continuous electricity. Prof. Kennelly emphasizes the point that the bad features are not so much due to its being single-phase as due to its being 75 per cent power factor. That is where the greatest disadvantage comes in. If the power factor of the three-phase generating and transmitting plant were 75 per cent instead of unity, the showing would be nearly as unfavorable as for single-phase. Mr. Mossman spoke of the $20,000 per mile as being too high. The transmission system would cost at least $700,000 for a scheme of this order of magnitude. The precise cost has to be settled according to just how many substations there are and just what distance away the generating station is. This, in turn would depend on the facilities for getting coal, etc. You would so locate your generating station as to minimize these costs so long as you did not sacrifice too much advantage in some other direction. I was conservative in putting the cost of fuel low, and the over-all efficiency of the generating station high, since I therein favored the single-phase system.

W. S. Murray (by letter): I have the following commentary and inquiries to make with reference to Mr. Hobart's paper:

1. The title of this paper, "The Relative Costs and Efficiencies of Polyphase and Single-Phase Generating and Transmitting Systems," does not properly indicate either the scope or the object of the paper. The statements in the first and last paragraphs with reference to the "single-phase railway system" and the continuous current system more clearly bring out the motive of the author.

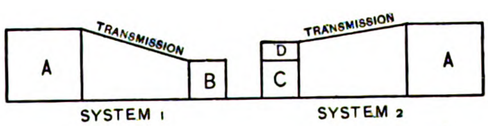
The attempt of the author to disqualify the single-phase system for railway electrification is so evident throughout the paper that all who read it must take this object for the

subject rather than the title given by the author. I consider an explanation is due from Mr. Hobart for this inconsistency.

2. Since the object of the paper is to discuss electric operation of railroads, why does Mr. Hobart stop at the substation? Note the table of efficiencies he has presented for the two systems. On the three-phase side the chain stops at the substation. Is there no line loss on the d-c. distribution system? Wireless transmissions have made great progress of late, but I doubt their practical application in such a case as this. Again, why throw in the step-up and step-down transformers on the single-phase side? Just because they are on the three-phase? Or because it balances the table, thus making four items for each table? As a practical example, they are not used in the case of the single-phase electrification of the New Haven road. Why charge up 8 per cent on line losses for the single-phase side, when, for example, our commercial experience allows a loss less than half that amount as the total average loss between generators and locomotives.

3. In the history of engineering, can any one point to the method Mr. Hobart has used to show the relation between the efficiencies of two systems—starting at the power house and working toward the railroad? I am glad he stopped at the substation, for had he arrived at the driving wheels of the train, which by the way would have something to do with the schedule, his explanations would indeed have been impossible.

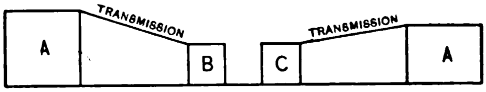
Mr. Hobart starts with 160,000,000 kw-hr. per annum as the outputs of the two stations. Now it is manifestly clear that unless the efficiencies of the two systems are identical from the generators to the driving wheels of the train, if one system provides the tractive effort necessary, the other will generate either too much or not enough power, depending on whether the efficiency of the second system is respectively greater or less than the first system. A graphical example of this is as follows;



In the above figure, A in both systems 1 and 2 represents the output of the station. B represents the amount of power that must be delivered to the drivers of the trains, and thus system 1 provides the exact amount needed. System 2, having higher efficiency than system 1, not only provides enough power $C = B$ for the railroad, but has left over an amount D (not needed). I believe this simple diagram will make clear the error Mr. Hobart has made in starting toward the driving wheels from the power house, rather than vice-versa.

Let us reverse the direction now and work from the tractive

effort requirements to the generating station, still adhering to our simple diagram:



B = *C* again represents the power requirements of the railroad. Both systems supply the exact amount required, but now note the difference in output between the two stations; the *A* of system **2** no longer equals the *A* of system **1**.

If, to produce an equal tractive effort, a system employing a chain of higher transmission efficiencies requires less output than another, is it fair to compare transmission efficiencies starting with equal outputs from each station? I think it is only necessary for me to point out this erroneous assumption to make clear the fact that the deductions must be equally erroneous.

Before leaving the question of transmission efficiencies, let us look at a table that has associated with it the facts of actual practice, and this time, following the plan as outlined in Fig. 2, we will trace the power requirements in the two systems from the driving wheels to the steam turbines, starting with—say 100,000,000 kw-hr. as the necessary driving wheel power.

Three-phase d.c.			Single-Phase.	
Kw-hr. per annum	Per cent efficiency	Items	Per cent. efficiency	Kw-hr. per annum
100,000,000		Drivers.		100,000,000
116,150,000	86	Loco. motors.	84	119,050,000
		Loco. transformers.	96.7	123,150,000
120,400,000	96.7	Loco. resistances.		
132,100,000	91	D-c. line.		
141,400,000	93.5	Synchronous converters.		
145,000,000	97.5	Step-down transformers.		
149,800,000	97	H. T. a-c. line.	97	127,000,000
153,750,000	97.4	Generators.	95.8	132,700,000
		Turbines.		
		$\frac{132,700,000}{153,750,000} = 86.6$ per cent.		
		$\frac{153,750,000}{132,700,000} = 1.16$ per cent.		

or 16 per cent more power for the three-phase d-c. system.

Thus it is apparent that *for the same tractive effort developed in the driving wheels of the trains* the number of kilowatt-hours to be generated in the single-phase power station is 86.6 per cent of the three-phase station, or, stated in another way, the

three-phase station will have to generate 16 per cent more power than the single phase station to accomplish the same result at the *driving wheels* of the train equipment.

Having now drawn attention to the attempt to disqualify the single-phase system by this fallacious treatment of the transmission question, I wish to point out a few isolated errors in assumption and design that Mr. Hobart has made.

Let us take a look first at Mr. Hobart's 8000-kw. machine. Now just why did he select this size. It is a rather odd one. I do not recall ever having seen this size of generator in print before, and certainly not on the floor of a power station.

By a selection of this size Mr. Hobart has admittedly and erroneously assumed it will carry him out of the environment of 1500 rev. per min. for the single-phase generator, as after he has allowed for the larger capacity made necessary by the star winding *using only two legs* and increased the copper for his 75 per cent power factor conditions, he has built the unit up until it represents in three-phase capacity a generator of 16,000 kw. Of course, had Mr. Hobart allowed his generators to retain the modest capacity of 5000 kw., then his double generator single-phase unit would not have been safe.

Notwithstanding, however, Mr. Hobart has calculated without his host, for there are other manufacturers who have built 1500-rev. per min. generators, whose three-phase capacity has been 14,000 kw., and have offered tenders on machines of 20,000 kw. capacity. Thus Mr. Hobart's double generator proposition fails. Two hundred and forty tons is indeed a weighty generator to charge up for a 16,000-kw. machine, when one of 14,000 kw. has already actually been built which weighs but 95 tons.

Before leaving the generator end of things, I am forced to draw Mr. Hobart's attention to the fact that his statements concerning steam economy at high speeds is at variance with the statements his company has advanced with reference to economies at low speeds. We will grant that two generators, each of half the capacity of one, weigh more than the one generator (and we reserve the privilege of using one), but his statements as to steam economy for the type of turbine used are contradicted by other advocates of the same type of turbine. However, it is all summed up when it can be stated as a fact that the manufacturers who have been in the business of real single-phase machinery can build *one* generator in the form of a single unit, large enough and with the same speed, to match up with Mr. Hobart's single unit three-phase machine. Let us not forget, however, that Mr. Hobart will owe us either a refutation or explanation of the low economy he applies to high economy, four-pole, 750-rev. per min. Curtis turbines. Throughout his paper in text and foot notes we are reminded constantly that he is being liberal with the single-phase. A too great liberality might do a great injustice to the three-phase. Why not be just? Say what it is, not less or more than it is. I might say Mr. Hobart

showed, for instance, great liberality in choosing that 8000-kw. generator, as 240 tons of single-phase generator was a far too liberal supply.

Now having shown the error in proposing the double generators let us have a look at some of Mr. Hobart's thoughts on generator design. It is evident that Mr. Hobart has had little to do with dampers—that is, field dampers. He tells us the loss in the dampers is just equal to the armature loss, and backs it up by quoting 13 kw. for the field damper of the single-phase generator and 13 kw. for the armature loss. Evidently Mr. Hobart has assumed that the damper has to neutralize the complete magnetic flux due to the armature turns. If it did, even then its loss would not be what he has stated. He evidently does not appreciate that the armature field is made up of two components, each revolving in opposite directions and of equal value. One of them is in synchronism with the rotor and is therefore not acted upon by the damper. The other component revolving in the opposite direction to the rotor flux is compensated for by the damper. Here therefore, Mr. Hobart's figures are reduced to one half. Now let us go a step further: On account of the long armature connectors necessary to a two-pole winding, and the short connectors inherent to the squirrel cage wound damper, the proportion again is cut in half due to the resistance of the damper being in that proportion to the armature, and so Mr. Hobart's figures sink to 25 per cent of their value.

Still in the domain of machine design, let us discuss for a moment Mr. Hobart's views on regulation. He says "Incidently the three-phase unity power factor installations will have some 6 to 8 per cent inherent regulation, whereas the inherent regulation of the single-phase 75 per cent power factor installation will be of the order of 15 per cent or worse, and will be thus so inferior as to require that some type of automatic regulators be provided."

Can it be possible at this late stage of generator design Mr. Hobart is not awake to the fact that an inherently poor regulation in a machine, which compared kilowatt for kilowatt with another of equal weight and better regulation, gives the best account of itself when measured on the scales of efficiency. The 6 per cent machine has no regulator, less kilowatt capacity and poor regulation. The 15 per cent machine has a regulator, more kilowatt capacity and perfect regulation. Thus the regulator pays for itself many times over. Besides this its inherent regulation is in marked economical contrast to the revolving mass of substation apparatus which the author recommends to buffet the short circuits of the line.

In conclusion, let us compare Mr. Hobart's hypothetical single-phase system with the actual single-phase system in operation on the New Haven road. He gives the single phase aggregate annual efficiency as 81 per cent thus involving a loss of 19 per cent. The aggregate loss between the steam turbines and the electric locomotives on the largest single phase road in operation

is 7 per cent; thus giving an efficiency of 93 per cent. Mr. Hobart's assumed losses are, therefore, 2½ times as great as the actual losses. Hence, there is nothing left but a choice between the theory propounded by the author in his paper and practice as we find it; which?

Edgar Knowlton (by letter): In the first part of Mr. Hobart's paper is a comparison of the weights of the three-phase 8000-kw. generator at 1500 rev. per min. and a single-phase 8000-kw. generator at 750 rev. per min. I believe that the weights of these two generators will be more nearly represented by 100 and 200 tons since this is the ratio of the three-phase ratings of the two machines and the reduction in speed will not greatly increase the weight of the single-phase machine.

A single-phase 8000-kw. 1500-rev. per min. generator is a practicable machine but, as explained above, its weight, cost, and efficiency, would vary but little from that of the same capacity machine at 750 rev. per min.

For the losses and efficiencies given a little further on I would be inclined to substitute the following:

THREE-PHASE 8000-KW., 100 PER CENT POWER FACTOR., 1500 REV. PER MIN.

Armature I^2R loss	25 kw.
Field " "	25 kw.
Core loss	115 kw.
Windage loss	100 kw.
Total loss	280 kw. (3.25 per cent)
Eff. (Excluding bearing friction)	96.75 per cent.

THREE-PHASE 6000-KW., 80 PER CENT POWER FACTOR

Armature I^2R loss	25 kw.
Field " "	40 kw.
Core loss and windage (excluding bearing friction)	215 kw.
Total loss	280 kw. (4.5 per cent)
Eff. (excluding bearing friction)	95.5 per cent.

SINGLE-PHASE 4000-KW., 75 PER CENT POWER FACTOR, 1500 REV. PER MIN.

Armature I^2R loss	17 kw.
Pole face winding I^2R loss	17 kw.
Field I^2R loss	33 kw.
Core and windage loss (excluding bearing friction)	215 kw.
Total loss	282 kw. (6.6 per cent)
Efficiency (excluding bearing friction)	93 4 per cent.

A comparison of the estimated losses is given in the following table:

	Loss	
	Estimate in the paper	Estimate as above
Three phase, 800 kw., 100 per cent power factor, 1500 rev. per min.	2.6 per cent	3.25 per cent
Three phase, 6000 kw., 75 per cent power factor, 1500 rev. per min.	3.5 per cent	4.5 per cent
Single phase, 4000 kw., 75 per cent power factor, 1500 rev. per min.	5.2 per cent	6.6 per cent

The differences in the weights and losses, however, do not affect Mr. Hobart's conclusions as to the relative cost of the two systems.

John B. Sparks (by letter): Mr. Hobart's comparison between the cost of single-phase and three-phase current at the distant end of the transmission line is of considerable interest in view of the fact that both systems of generation and transmission are being adopted on the Continent for single-phase railways. While Mr. Hobart calculates single-phase current to be 9 per cent more costly at this point, the additional cost in the three-phase case of the rotary machinery required to transform to single-phase and the attendant losses practically balance this, so that there is little to choose between the two systems. In most cases indeed the all-single-phase proposition will be found strictly the most economical, but where the current may be used for power as well as for traction, generating and transmitting three-phase may be found most satisfactory.

Mr. Hobart's arguments as to the comparative size and cost of single-phase and three-phase generators are not very clear. A simple calculation shows that the three-phase rating of any machine is 1.73 times the single-phase rating (using two phases in series) on the basis of equal current density, or about 1.4 times on the basis of equal armature copper losses. The actual figures, however, obtained from a well-known Continental firm for four generators ranging from 2500 to 10,000 kw. single-phase output show an average three-phase rating of 30 per cent greater than the single-phase rating (the full-load efficiencies are only about 0.5 per cent greater and the regulation full-load to no-load 3 per cent less in the case of three-phase working). Assuming unity power factor for the three-phase machine and 0.75 power factor for the single-phase machine, the latter will weigh and cost, therefore, about 1.75 times as much as the three-phase machine of the same kilowatt output. It is not clear why Mr. Hobart has not taken the same transmission line pressures in the two cases; presumably the increased cost due to the higher single-phase pressure is covered by there being two instead of three insulators per pole. It would have been more economical to have taken a larger total copper section in the single-phase case.

It would be interesting if Mr. Hobart would complete his synthesis of the cost of current per unit by including the distribution costs and losses and stating the cost per unit at the trains. Continuous current at 600 to 1200 volts costs, he concludes, only 18 per cent more than single-phase current at from 6000 to 12,000 volts. The cost of the distribution and contact wire system in the latter case is very much greater than the cost of the distribution and third rail system for direct current working, and the cost per unit at the trains might consequently be even greater for single-phase current. In view, however, of the admitted higher cost of single-phase as compared with direct current

equipments and the higher maintenance costs in the former case, any slight superiority of the single-phase system in the cost of current supplied to the trains is of little importance.

Roger T. Smith (by letter): Incidentally the figures in Mr. Hobart's paper serve to show the advantage of the purchase of electricity for railway traction purposes wherever the railway load factor is low, and indeed other things being equal (which is seldom the case) it is a great advantage to a railway company to buy its electrical energy from a supply for general purposes, where that energy is only one item tending to increase the diversity factor of the whole supply, and to pay for it, as it is used, out of revenue, rather than to be obliged to pay interest on capital invested in a generating station which may for many years be a burden on traffic returns out of all proportions to the receipts.

Before dealing with the argument it may be of interest to refer to one or two points which in themselves do not affect the argument.

Dealing with the table of substation machine load factor and "all-year" efficiency, the figures may be compared with those of a substation supplying continuous current for the Hammersmith & City Railway forming a small item in London suburban electric railway service. The substation is equipped with La Cour motor converters and not with synchronous converters and the average power factor is never as much as 1 per cent below unity. The machines work in parallel with a battery whose input and output is controlled by automatic boosters. For 1911 the machine load factor was 63.9 per cent and the all-year efficiency 84.1 per cent including the battery and 86.6 per cent excluding the battery. Turning to the next table, the two substations supplying this railway (with only 10 miles of single track) for an annual output of 8,000,000 kw-hr. had a combined load factor of 60 per cent and cost 0.12 cents per kw-hr. for wages, oil and stores. Surely the machine load factor as defined for substation performance, is the correct load factor to use for generating station as well as substation performance? The rated output is the continuous capacity of the station and the percentage of this obtained during the hours the machines actually run alone tells the station engineer if his plant is used in the most economical way. Skilful management can increase the machine load factor while the maximum-power load factor may remain nearly stationary.

A small generating station belonging to the Great Western Railway, equipped with reciprocating engines, supplies the two substations, of which one has already been referred to, with three-phase current. It has an output of 10,000,000 kw-hr. for traction only, yet it may be interesting to give the figures corresponding to note (9) of Mr. Hobart's paper. During 1911 the average B.t.u. of the coal used was 11,900, *i.e.*, the calorific value is 3.46 kw-hr. per lb. This for 100 per cent efficiency

between furnace and feeders corresponds to 0.288 lb. per kw-hr. but the actual thermal efficiency was 7.9 per cent. Comparing this generating station with that referred to in the note for the West Jersey & Seashore Railway the results for 1911 for coal of 11,900 B.t.u. are as follows:

Year	Output, traction and lighting, in million kw-hr.	Lb. of coal per kw-hr. output	Overall efficiency per cent
1911	11.8	3.65	7.9

Coming to the argument itself regarding the efficiency, from the steam turbine to the distribution system, of three-phase continuous current supply as compared with single-phase supply, the actual advantage of one over the other depends wholly on the single-phase power factor assumed. Mr. Hobart has taken this average power factor at 0.75, and while any figure given must be accepted with caution (since in the United Kingdom charges are always based on kilowatt-hours so that kilowatt-ampere hours are not metered) I think for British railways 0.75 may be unnecessarily low. There are only two single-phase railways in the United Kingdom, the Heysham-Morecambe line of the Midland Railway and the South London Suburban lines of the London, Brighton & South Coast Railway.

For the Heysham line, with an intermittent service of about twelve trains each way per day, average results are of no use since when no trains are running and the line is only charged there is a leading current. The tendency of this charging current is to raise the power factor, but the inductance of the line outweighing its capacity, the general effect of the line when trains are running is to lower the power factor. On the official trial runs the power factor of the low tension energy during a set of tests giving maximum acceleration (closely corresponding to suburban running) was 87 per cent and during a set of non-stop runs between Morecambe and Heysham (with a large percentage of coasting) the power factor was 86 per cent. Both figures will be reduced at the generating station by the inductance of step-down transformers on the train and by the line, but these were not measured. On the Brighton Railway the power factor during trial runs works out as 80 per cent but the average power factor of the generating station has not been measured. From these two results, one during the test of a service on the Midland electrified system imitating suburban traffic and the other during the test of a typical London suburban service, it would seem that Mr. Hobart's estimate of average power factor may be too low. The figure of 0.75 is to be accepted with caution and there is every probability that in some actual railways it is exceeded, while means for improving the power-factor of the whole supply are not beyond the power of the electrical engineer.

Perhaps the most interesting part of the paper is the general

conclusion, where the combined use of both three-phase- continuous current and single-phase current are advocated to deal with different classes of traffic—a view first publicly ad-advanced as far as Mr. Hobart is concerned in his Royal Engineer's lecture at Chatham in 1909.

Mr. Aspinall's statement made before the Institution of Civil Engineers and quoted by Mr. Hobart puts the matter very clearly, and it may be said that there are very few railways in Great Britain and Ireland possessing a suburban service of sufficient importance to warrant electrification, in which the stopping trains do not run over roads kept entirely separate from those used by the long distance traffic. If this is not the case for the whole of the suburban traffic it certainly is so in the majority of cases. For instance the London & North Western Railway has under consideration the electrification of some 80 miles (single track) of suburban road. This is entirely distinct from its main line although the Euston and Watford electric line will run for many miles beside its main line. The system on which the company must electrify its suburban railways is settled for it by the fact that the rolling stock must run over sections already electrified on the third and fourth rail continuous current system, but it is difficult to see what possible difference this could make to the use of any other system of electrification it may choose to use on its main line should the time ever come for it to be electrified.

On the other hand there are English railways where the suburban system forms such a large portion of the whole system and is so intimately interwoven with the main line that two systems would be bad engineering. The Brighton Railway is such a case and it has chosen one system to suit all conditions.

H. M. Hobart: The plan adopted by Mr. Murray, of carrying out the tabular comparison in his discussion, is of interest and I am of the opinion that, by suitably modifying and extending the conception, instructive results may be obtained. I propose to illustrate by an example the method by which we may, in any given case, establish a comparison of the power required at the generating stations for each of the two systems under discussion.

A hypothetical railway's rolling stock comprises the equivalent of 70 trains, each train consisting of five, 60-seat passenger cars, or a total of 300 seats per train.

Let the *average* service provide a schedule speed of 25 miles per hour, and let the average distance between stops be one mile. If the average duration of each stop is 20 seconds, then, since there will be 25 stops per hour, the average speed from start to stop will be

$$\frac{3600}{3600-25\times 20}\times 25.0 = 29.0 \text{ miles per hour.}$$

For good rolling stock operated over a well-constructed straight and level track, the energy required at the axles may be estimated from the formula

$$\text{Watt-hours per ton-mile} = 0.074 \times \frac{S^2}{D}$$

where S = average speed from start to stop, in miles per hour (= 29.0)

D = average distance between stops in miles (= 1.00)

Thus we have:

Energy required *at axles* $= 0.074 \times \frac{29^2}{1.00} = 62$ watt-hr. per ton mile.

For such a service the overall efficiency of the electrical equipment on the train will be about 70 per cent, irrespective of whether continuous-electricity apparatus or single-phase apparatus is employed. Consequently the input *to the train* will be

$$\frac{62}{0.70} = 89 \text{ watt-hr. per ton mile.}$$

This value corresponds to the condition of test runs made with well-designed and well-constructed rolling stock over well-built straight and level track in calm weather. The conditions of actual practice may be assumed, in this hypothetical case, to increase the consumption of the train up to the gross average of 115 watt-hr. per ton mile and this value may be considered as being sufficiently liberal to allow for non-productive train movements. By methods* known to be correct, it can be estimated that the weight of such a 300-seat train will be:

210 American tons when the motive power is supplied by continuous current train equipment.

270 American tons when the motive power is supplied by single phase train equipment.

Consequently for the consumption per train we have

$210 \times 0.115 = 24.2$ kw-hr. per train mile for the trains equipped with continuous-current apparatus and

$270 \times 0.115 = 31.0$ kw-hr. per train mile for the trains equipped with single-phase apparatus.

Let the requirements of the service be such as to call for 50,000. miles per train per annum for each of the 70 trains. Then the total annual consumption at the trains amounts to

$70 \times 50{,}000 \times 24.2 = 85{,}000{,}000$ kw-hr. for the continuous current trains and

$70 \times 50{,}000 \times 31.0 = 108{,}000{,}000.$ kw-hr. for the single-phase trains.

We may throw these results into a tabulated form similar to that preferred by Mr. Murray and may complete the calculations in the way he has outlined. This is done herewith.

*These methods are explained in the author's treatise entitled "Electric Trains" and were employed and discussed at the July 1910 meeting of the Institution of Mechanical Engineers in London. Considerations of space render it inexpedient to set forth here the steps in the estimation of these train weights.

Three-phase, synchronous substation system. (Generator pressure = 11,000 volts)			Single-phase system without transformers except on train (Gen. pressure = 11,000, volts)	
Kw-hr. per annum	Per cent efficiency	Items	Per cent efficiency	Kw-hr. per annum
59,500,000	——	Drivers	——	75,500,000
85,000,000	70.0	Train equipments	70.0	108,000,000
88,500,000	96.0	Circuits from substations	——	——
97,200,000	91.0	Substations	——	——
102,000,000	95.5	High-pressure line	89.4	121,000,000
105,000,000	97.4	Generators	94.8	127,500,000

Since $\frac{127,500,000}{105,000,000} = 1.21$ we see that for the single-phase system 21 per cent more energy is required to be provided annually by the steam turbines in the generating station.

Thus for supplying the needs of the stipulated passenger service, 21 per cent more energy must be delivered annually from the power house turbines when the single-phase system is employed than when the three-phase system with synchronous substations is employed.

I am aware that the percentage at which I have arrived applies exclusively to the particular assumptions and service relating to the hypothetical case which I have studied. For a more sparse passenger service with greater average distance between stops, and for freight service the results will be less unfavorable to the single-phase system, but there is a big margin to be overcome before the 21-per cent. greater amount of energy required by the single-phase system is wiped out. I have not dealt with the far greater *capital outlay* required for single-phase rolling stock, as Mr. Murray does not mention the question of the relative capital costs of rolling stock for the two systems. Mr. Murray is wrong in employing efficiency as a criterion of merit. It is necessary to also consider the capital outlay by which that efficiency has been attained. Mr. Murray gives the efficiency of the high pressure line on the New Haven road as being 97 per cent. Obviously by trebling the outlay for line copper he could increase this efficiency to 99 per cent. But it would not be true economy to do so. The highest economy might correspond to half as much line copper, even though the efficiency is thereby decreased to 94 per cent. Presumably 97 per cent was the right value to adopt for the case he had in hand but it has no bearing whatsoever on the appropriateness or otherwise, of the line efficiencies adopted in my estimates.

In the above tabulated comparison I have left out the step-up transformers, to bring the comparison into conformity with Mr.

Murray's preferences but it is obvious that this policy will, on extensive systems, mean resorting to several smaller generating stations instead of a very few large ones, thus involving lower load factors and also requiring the location of the generating stations at other than the most favorable sites and thus decreasing their commercial economy. I have taken the three-phase transmission line's efficiency at 95.5 per cent, the value taken in my paper, but instead of taking the single-phase line at the efficiency of 92.0 per cent which corresponds to a 15 per cent higher transmission pressure as explained in foot-note 10 of my paper, I have reduced it to 89.4 per cent the value which, as I explain in that footnote, corresponds to the same outlay for copper as for the three-phase line and the same generator pressure of 11,000 volts. This change is also necessitated by Mr. Murray's preferences for eliminating step-up transformers.

Mr. Murray may take exception to my plan of basing my calculations upon the requirements of a single class of passenger service but I would ask him to observe that corresponding calculations can be made for any other class of train service and that the case I have taken represents an exceedingly important one. I frankly admit that for a sparse long distance passenger service with infrequent stops, and for freight service, the case will not be so desperate a one for the single-phase system. For such a system as the New Haven, where several classes of rolling stock will be operated electrically, each class can be analyzed in accordance with the plan I have illustrated, and the aggregate taken for the road's entire equipment. For cases where the single-phase system shows up to be the most economical when both capital and operating costs are taken into consideration, that system should obviously be the one put forward. My own personal opinion is, however, that such cases will be rare. I have stated in the paper that I am of the opinion that engineers have greatly magnified any difficulties associated with the use of both systems, each dealing with its appropriate class of rolling stock. This is also, as stated in my paper, the view of Mr. J. A. F. Aspinall, General Manager of the Lancashire and Yorkshire Railway, and, also as we find in this discussion, a close approximation to the view of Mr. Roger T. Smith, Chief Electrical Engineer of the Great Western Railway. Both of these gentlemen have been responsible for many years for extensive electrified sections of main-line railway and each dissents strongly from the view that there is usually any need for using other than the most appropriate system for each class of traffic.

As regards the rest of Mr. Murray's criticisms of my paper—they are chiefly directed to suggesting that I have painted too lurid a picture of the conditions in three-phase generators when employed for providing a supply of single-phase electricity direct to railways without the interposition of substation machinery. My answer is to quote from the January 1912 issue of the PROCEEDINGS A.I.E.E., Mr. B. G.

Lamme's description of the single-phase generators as finally modified to withstand the conditions of operation on Mr. Murray's road.

Mr. Lamme states:

" There is one feature in connection with the generating plant which has not had its full significance brought out before. I refer to the use of 11,000 volt machines with one terminal grounded. These generators have three-phase armature windings of the star type with one of the three terminals permanently grounded. Two of the legs of the star are used for the single-phase circuit, while the third leg is used in connection with certain three-phase work. Across the railway phase the potential is regulated for 11,000 volts normal, by means of an automatic regulator in connection with the fields of the generator. The third leg gives a little higher voltage normally, due to the small load which it carries at present. In consequence, its voltage is usually somewhere between 11,000 and 12,000 volts. Assuming this at 11,000 volts, then in these machines we have an equivalent, as far as insulation stresses go, of a three phase generator with grounded neutral *with* 11,000 *volts between the neutral and the terminals.* This therefore is practically the equivalent of *a* 19,000 *volt three-phase generator with the neutral grounded.* It is more than this, as it is the equivalent of a 19,000 volt machine with the neutral grounded and *with the terminals tied directly to* 100 *miles* of 11,000 *volt overhead system without the interposition of transformers.* This is a very abnormal condition compared with anything that is being done in this country at present. 16,500 volts is the highest generator now used on a large scale, as far as I know. But here we are actually running under conditions corresponding to 19,000 volts with the hardest kind of service and with an over head line without transformers which is going to be extended to about 500 miles. Under these conditions the generating plant has made an extremely good record, as indicated by Mr. Murray in his table of delays due to power house. I may say that for about two years, or possibly more, there has been practically no trouble as far as the generators are concerned; that is, any trouble which would shut down the system. There has been one breakdown in one machine, but a careful examination of this one case developed no cause for the breakdown other than a damage to the insulation in originally putting the coil on the machine. There were no signs of deterioration of the insulation, and the insulating materials on the damaged coil appeared to be as sound and flexible as when first put on. So here we are running machines *at the equivalent of* 19,000 *volts on a three-phase system,* and during two years there has been continuous service. This is a most excellent record. If we compare this with a late practice, now being advocated here and there, of winding large turbo generators for low voltage, such as 2,200 volts, and then stepping up to voltages, even as low as 6,600 volts, we can see what a *wonderful thing* this New Haven operation is. In some cases at the present time, 11,000 volts, or even 6,600 volts on the generator is being condemned as bad practice because of dangers from line voltage, surges, lightning and such things, but in this New Haven plant there are 100 miles of overhead system under conditions where it is exposed to surges of the worst sort."

In the above extract Mr. Lamme protrays far more vividly

than I have done in my paper, various features in which single-phase generators supplying electricity direct to the trains are more elaborate, heavy and expensive than three-phase generators supplying substations. I stand by my figure of 240 tons for the weight of the 8000 kw., 75 per cent power factor, 25-cycle, single-phase generators. I am aware of instances in England and America where much lighter single-phase generators have been installed for railway work. I am also aware that they have been utter failures.

Mr. Roger T. Smith gives us the advantage of some carefully prepared results from his own experience. His data for the over-all efficiencies of substations and for the outlay for wages, oil and stores per kw-hr. are not quite so favorable as those in my paper, but it must be noted that I have dealt with large units. It had been my hope that my paper would serve to bring forth in the discussion a large amount of specific data from the experience of other engineers, such data, for instance, as this which Mr. Roger Smith has contributed, as also the data contributed by Mr. Knowlton and Mr. W. C. Smith. It is a most laborious task to derive such data for concrete cases, and engineers are tempted to base their conclusions on abstract reasoning. Sooner or later, however, recourse must always be had to rigorous quantitative comparisons of the commercial economies attainable by the alternative methods by which the desired results may be reached. Often this is not done till after large sums have been expended on the wrong system but it might just as well be done in the first instance. Great economies would thereby be effected and electrification propositions would command more respect from the railways.

Mr. Sparks and several other contributors to the discussion have expressed the opinion that the comparisons should have extended from the generating station to the train and should not have stopped short at the substations. I have briefly met this criticism in the section of my reply which dealt with Mr. Murray's remarks. I have dealt very thoroughly with the rolling stock end of the comparison in various contributions to British engineering societies and on these occasions, the chief criticism has been that I appeared not to realize that the grave disadvantages of single-phase rolling stock were far more than offset by the advantages of single-phase methods in all *other* parts of a railway electrification system. The results arrived at in the present paper show that the disabilities of single-phase methods extend right through the system, from and including the generators in the station, to and including the motors on the train.

DISCUSSION ON "OPERATION OF TWO ALTERNATING-CURRENT STATIONS THROUGH PARALLEL CIRCUITS AND THE DISTRIBUTION OF LOAD AND WATTLESS CURRENTS BETWEEN THEM" (WELSH), PORTLAND, ORE., APRIL 18, 1912. (SEE PROCEEDINGS FOR MARCH, 1912.)

(Subject to final revision for the Transactions).

Waldo V. Lyon (by letter): I gather from this paper on parallel operation that Mr. Welsh uses the simple method of analysis which assumes that each alternator has a constant synchronous reactance. The results obtained by this method, while useful, are often at considerable variance with those met with in practise.

At the beginning of the seventh paragraph Mr. Welsh says: "When two alternating-current units are operating in parallel, their induced electromotive forces are opposing each other, and if they are equal in magnitude and in exact opposition, the output of the two units must be equal both in the energy and the wattless components of the current." This statement is true only when the two alternators have equal armature resistances and equal synchronous reactances. It is here understood that the alternators are connected in parallel by lines of no resistance or reactance, although by the proper interpretation of armature resistance and reactance the statement will apply to the case in which two alternators are connected in parallel through transmission lines. The terminal voltage of the alternators would in this latter case be measured at the point of parallel connection.

The writer discussed this question of two equal alternators in parallel at considerable length in the *Electrical World* for December 28, 1907. In this discussion and in what follows the writer assumes that the alternators have equal resistances and equal synchronous reactances. He understands that this hypothesis is not correct and in extreme cases may lead to erroneous conclusions. But it is a method in general use for determining the approximate conditions that exist and is, he believes, the method Mr. Welsh uses. The division of the load between two alternators depends primarily upon the speed-load characteristics of the prime movers. If these characteristics are flat the division of the load is in an unstable condition, but with characteristics which droop sufficiently the load carried by each prime mover is fixed by the total load required. Thus if the change in the armature losses produced by field variation can be neglected, the division of the load will not be affected by varying the excitations of the alternators, provided, of course, the terminal voltage is kept constant so that the total load will be unaltered.

If this is true any interchange current that is produced by field variation is in quadrature with the terminal voltage of the alternators, and the generated voltages are changed both in magnitude *and in their relative phase displacement*. Thus Mr. Welsh has no justification in showing them in phase as in Figs.

1 and 3, and the conclusions he draws from this construction are not correct.

If the resistance in each alternator circuit is comparatively large so that the variation in the copper losses should not be neglected, a solution can be obtained if it be assumed that the speed-load characteristics of the prime-movers are identical and that the rotational losses are constant. In this case the powers supplied to the alternators are equal, and any difference in the outputs can only be accounted for by a corresponding difference in the copper losses. This gives the relation

$$\frac{I_0'}{I_0''} = - \frac{r\,I''}{V + r\,I'}$$

In which I'_0 and I_0'' are respectively the energy and wattless components of the interchange current with respect to the terminal voltage V, and I'' and I' are respectively the wattless and energy components of the current, supplied to the load with respect to the terminal voltage V. r is the armature resistance of one generator. The minus sign has this significance: If the load is inductive the power supplied by the alternator will increase as the excitation is diminished.

This relation shows that with a load of unit power factor, such as Mr. Welsh assumes, the interchange current is wattless with respect to the terminal voltages and the generators still continue to deliver equal powers in spite of differences in field excitation. This conclusion has been verified in the electrical engineering laboratory of the Massachusetts Institute of Technology for the case of two 15-kw. generators. It is only when the power factor of the load is other than unity that changing the excitations can cause a shifting of the load from one alternator to the other. As an example of the amount by which the load may be shifted by change in excitation take the following case:

With full load current let the Ir drop in one alternator and line to the point of parallel connection be 15 per cent. of the terminal voltage. Assume that the load is inductive and requires twice the full load current of one alternator at 0.707 power factor, and that the interchange current produced by change in excitation is equal to the full load current.

Then

$$\frac{I_0'}{I_0''} = \frac{0.707 \times (2 \times 0.15)}{V + 0.707 \times (2 \times 0.15)} = 0.17$$

Thus the alternator with the smaller excitation will take 58 per cent of the total load and one with higher excitation will take 42 per cent of the total load.

The power transferred from one alternator to the other by governor adjustment which causes an angular displacement of δ in the internal voltages E is

$$P = V^2 \left(\frac{x_s}{z_s^2} + \frac{X}{2\,X^2} \right) \tan \frac{\delta}{2}$$

in which V is the constant terminal voltage of the alternators, x_s and z_s are the synchronous reactance and impedance of one alternator, and X and Z are the equivalent reactance and impedance of the load supplied. In this case it is necessary to increase the internal voltages equally in order to maintain a constant terminal voltage.

The interchange current produced by this relative phase displacement is

$$I = \frac{E}{z_s} \tan \frac{\delta}{2}$$

The internal voltage E varies with the power factor since $\frac{E - V}{V}$ is the regulation of the generator.

This shows that for a given angular displacement of the internal voltage both the interchange current and the power transferred depend upon the power factor of the load, and the writer does not understand why Mr. Welsh makes a contrary statement.

This same equation for power transferred gives the synchronizing power when the displacement δ is produced by hunting, except that in this case the internal voltages are constant, and $\tan \frac{\delta}{2}$ should be replaced by $\sin \frac{\delta}{2}$. The equation now emphasizes the well-known fact that alternators operate better in parallel on an inductive load, since for a given angular displacement the power transferred from one to the other is greater.

The effect of increasing the ratio of resistance to reactance as would occur when the alternators are paralleled through equal transmission lines, can also be determined from this equation and is, I believe, not in accord with the explanation given by Mr. Welsh of the effect of the resistance and reactance drops in the connecting transmission lines.

The case of two dissimilar alternators, which is practically the same as that of two equal alternators connected in parallel by lines with unequal constants, is not quite so simple from the analytical standpoint, but the general qualitative results are much the same.

H. Y. Hall: I certainly do not agree with some of the conclusions reached in this paper. I agree somewhat with the criticisms that have been made in the discussion of Mr. Lyon. It is not possible in alternating-current system by mere adjustment of voltage to shift the load from one machine to another, although it is possible in a direct-current system. In the alternating system the division of loads depends entirely on the characteristics of the governors, and a relative setting of the governors and the machines, and not upon a field adjustment. It would be possible to pull the field off the alternating current generator and still carry the load, but if you pull the field off a direct-current ma-

chine, the current would increase. Otherwise the current would lag. It depends primarily on the setting of the field rheostat and the division of the load. That is borne out by practice. I have operated some of the largest stations in the country and that is not only so in respect to the division of load between machines in one station, but is also true in respect to the division of load between two different stations running in parallel. I have in mind the 74th street station of the Manhattan Railway and the 59th street plant of the Interborough Rapid Transit Company.

The Chairman: Mr. Hall has contributed a very valuable item. I would suggest that where the question of stations is involved, and where there may be some considerable resistance between the stations then there begins to come in the effect of load distribution due to change of excitation, other things being the same, but he has done us a valuable favor in pointing out the real control of load distribution is not in the governor but in the rheostat.

P. M. Downing: I am inclined to take the same view of this matter as that of the last speaker. There is no question but what the division of load not only between generators of the same station, but also between different stations feeding into a net work, must of necessity be taken care of by governor adjustment and not by field adjustment. With any fixed position of the governor, a certain amount of energy is delivered to the generator. This cannot be changed without changing the governor.

By adjusting the field you can change the form of the energy delivered by the generator, but you cannot change the amount. What really occurs when you change the field adjustment of any piece of synchronous apparatus operating in parallel with another is that you change the power factor on that machine; in fact the division of load and wattless current between stations feeding into any net work are handled entirely independent of each other. On a net work supplying power over a large territory, the power factor will be low and there will be considerable wattless current to be taken care of.

In the central part of California it has been the practise for several years past to operate a number of generating stations in parallel to feed a common net work. At present there are 15 or 20 of these, the greater part of them being hydroelectric, with two or three steam turbine installations.

The total mileage of lines supplied is, approximately, 1500, exclusive of the low-voltage distributing circuits in cities and towns.

The steam turbines are located in the larger cities and while they run in on the general network with the hydroelectric plants, they ordinarily carry but little load. They are, however, often called upon to carry a full load of wattless current, and thereby serve as voltage regulators and are always able to pick up the load in case of transmission line troubles.

A few years ago when the Pacific Gas and Electric Company

constructed its first transmission line, there was but little demand for electric power, and the load was small. Considerable trouble was had with voltage regulation at the receiving end on account of the charging current of the line boosting the voltage.

This trouble was so pronounced that it became necessary to put in reactance coils to neutralize this leading current. With the increased power load and the resulting low power factor, it was found that not only was the leading current due to the capacity neutralized, but there was a heavy lagging current.

Today we have installed synchronous condensers where once stood the reactance coils. These machines are installed solely for regulating purposes. They are arranged to be operated automatically and are doing it so well that the voltage regulation has been greatly improved.

W. A. Hillebrand: With regard to this question of distribution of the load by means of field adjustments, Mr. Lyons has pointed out a case in the laboratory using two 15-kw. machines. He was able to make a difference in the adjustment of the load simply by field adjustments. It seems to me, there is a marked difference where there are two machines in operation of perhaps equal capacity, constituting the only generators in the system, and which are operated at the opposite ends of the transmision lines. That case is quite different from the case where you have a large central station, or a large group of stations, and you attempt to swing the system simply by changing the field adjustment. It seems to me that it is possible to produce a certain adjustment of load where you have two machines of approximately the same capacity.

Lester McKenney (by letter): The paper by Mr. Welsh would have been of more practical importance had the subject of governor adjustment received the consideration which it deserves in a paper of this sort. With transmission lines and station circuits as usually constructed the question of satisfactory parallel operation resolves itself into one of governor adjustment, assuming that the units have been properly designed.

In order to insure proper division of the load between the generators operating in parallel on a system, the governor of the prime movers are adjusted for a definite drop in speed from no load to full load. Two per cent may be taken as a fair value. With this adjustment of the governors, neglecting the I^2R losses in the line, the division of any additional load thrown on the system is independent of the line or circuit constants. It will be evident that there must be a certain speed and governor position for any specified load. If the circuit between two generators consisted principally of resistance, and we should attempt to transfer load from No. 1 to No. 2 by rheostat adjustment, we would find that No. 2, in order to take more load would have to slow down in order that the opening of the valves or gates of the prime mover might be increased and the additional power required supplied No. 1, upon dropping part of its load would have to speed up to

reduce the valve or gate opening in order to reduce the power supplied to the amount required by the remaining load, such slowing down of one unit and speeding up of the other would be impossible if the resistance of the connecting circuit was such that parallel operation would be possible. The transfer of load from one generator to another by rheostat adjustment, when the governors are adjusted for satisfactory parallel operation, is therefore, possible.

With the governors adjusted for constant speed from no load to full load, and with the connecting circuits consisting principally of resistance, the transfer of load from one generator to another by rheostat adjustment is possible, and I assume that this is the governor adjustment which the author has in mind. The division of the load between the generators may also be materially affected by the line resistance and reactance. The transfer of load by rheostat adjustment, and the effect of the line resistance and reactance upon the division of the load would, under these conditions, be lost sight of in the erratic fluctuation of load caused by the lack of any tendency to load division on the part of the prime movers. Due to this erratic fluctuation of load the parallel operation of generators with governors so adjusted is unsatisfactory.

With the governors adjusted for a rise in speed from no load to full load parallel operation would be impracticable.

If the governor of one of two or more generators operating in parallel is adjusted to increase the gate opening, the generator must necessarily take more load independent of the circuit conditions, otherwise the generator would speed up and pull out of synchronism. In making this adjustment, the speed of the entire system is slightly increased.

Referring again to the connecting circuit consisting principally of resistance and considering the case where the governors are adjusted for a drop in speed from no load to full load, it is evident, from a study of the polar diagram, that when it is attempted to transfer load by rheostat adjustment, the generators automatically adjust the phase displacement of their electromotive forces, the electromotive force of the generator tending to drop its load advancing in phase; so that a resultant electromotive force is produced which will cause the current in the local circuit to be displaced 90 deg. from the induced electromotive forces. Should the resistance so far exceed the reactance that the 90 deg. displacement could not be obtained, the generators would drop out of synchronism.

The paper by Mr. Welsh does not, therefore, disclose any new methods of adjusting the wattless current and load on generators, working under practical operating conditions.

J. W. Welsh: The subject matter of this paper was suggested by the experience of the writer in the load dispatching system of the Pittsburgh Railways Company. We had there two plants operating in parallel one about 4000 kw. and the other about

21,000 kw. capacity. It is the duty of the load dispatcher to distribute the load between these two plants and order on and off machines at substations which are fed from these plants according to the variations of the load. He also directs the setting of the bus bar voltage at each plant. The bus bar voltage is controlled by an automatic regulator and of course the speed is controlled by governors. It was noticed in the operation of this system when the bus bar voltage was raised at one plant, that it was possible to shift the load between the two stations. These plants are connected through three cable lines, that is, they operate in parallel over three separate circuits to which the load is independently connected. I had always been of the opinion that it was impossible to produce any definite transfer of the load without going to the governors and making a change in the setting of them. We found, however, that a transfer of load occurred when the bus bar voltage was changed by field adjustment.

I believe the criticism of the fact that it is possible to cause a transfer of load by field adjustment is due to a misconception of the point of view of the writer in this paper, and that is this: It is of course obviously impossible to make a machine at one station carry more load without giving it the necessary driving power for the increase in load. In other words, it is necessary that there should be a change in governor setting to carry any increase in load that may come to that station from any other cause. That is explained in the paper. The engine or turbine governors at each station, being automatically controlled, at once admit the necessary steam at the station receiving more load, and decrease the steam admitted at the station from which the load is taken. The assumption is made that the phase angle doesn't change and that the necessary steam is admitted by such change in governor setting as is required to prevent any change in phase angle of the electromotive forces. If you hold the phase angles constant then a change in field adjustment as shown by the diagrams will bring about a transfer of the load. Of course that is a situation that does not occur very often and only occurs to a limited extent. In other words the change in load, by field adjustment is in proportion to the resistance component of the cross current and that is usually a minor component particularly on a transmission line where the inductive reactance is high. On a cable system, however, the resistance is usually higher than the reactance. In our case, the paralleling circuit is a cable between stations.

R. Howes: I would like to ask Mr. Welsh regarding the load speed curve of the governors which he used. Were the governors designed for a flat speed at all loads or how much reduction in speed was there from no load to full load.

J. W. Welsh: I am not able to say definitely. I imagine about 4 per cent, but I may say these diagrams are merely made to represent pictorially what happens; in every case, it is possible of course for the attendant to change his governor setting

as the load changes, but that was unnecessary in the case I spoke of where the change is secured in the load by field adjustment. I am not sure that 4 per cent is the actual amount.

F. R. Brainard (communicated after adjournment): Mr. Welsh concludes, among other things, that a change in relative field strength of two alternators in parallel may change the distribution of load between them. If he refers to the case in which the machines are constrained to operate in synchronism through some other condition than merely paralleling them electrically, *e.g.*, if the rotors are mounted upon the same shaft or if they are driven by synchronous motors which take current from the same source, then the following criticism does not apply. Also, he may have in mind the slight change in efficiency due to a change in power factor. This will usually be too small to observe, however, and probably he does not refer to this. But with these possible exceptions, the writer cannot agree with him in the conclusions which he deduces.

For every prime mover with his governor, there is a certain definite relationship between speed and power delivered, and for machines which are to operate alternators in parallel, the governors *must* be adjusted so that the speed will decrease as the load increases (unless the governors are interlocked). Hence, if the load increases on one unit, it must increase on *all others* in parallel with it. In other words the problem is entirely a mechanical one if the machines stay in synchronism, and the electrical conditions have nothing to do with the distribution of load between them. However, the question as to whether parallel operation will be satisfactory or not, is largely an electrical one and as Mr. Welsh states, a certain amount of inductance is necessary, although on the other hand too much inductance may cause the machines to fall out of step because of insufficient synchronizing power.

The following is an attempt to determine in a general way the design of transmission lines over which parallel operation is contemplated.

Consider the case of two alternating current plants, each serving its own load through separate feeders but connected in parallel by means of a tie line. The problem is to determine the relationship between the resistance and reactance necessary to give the best results. If the amount of power transmitted is small compared with the maximum capacity of the line, it can be easily shown that the value of reactance x which gives the maximum "synchronizing power" (*i. e.*, the maximum kilowatt per degree displacement of station voltages) for a fixed resistance r and for equal generator and receiver voltages is, $x = r$. (See note 1.) Also, it can be shown that the value of reactance which gives the maximum capacity to the line (capacity for the transmission of power) under the same conditions is, $x = \sqrt{3}\, r$. If the generator and receiver voltages are unequal but constant, the ratio of reactance to resistance which

will make the capacity of the line maximum with a *fixed resistance* depends upon the ratio of generator to receiver voltage, as shown by the curve Fig. 1. (See note 2.) In this and also the previous discussion the drop due to static charging current is neglected. Generally it will be negligible since the charging current is supplied from both ends of the line, but this is not always true. Hence it would seem that the best value for x is usually between $x = r$ and $x = \sqrt{3}\, r$.

Of course the practical conditions will seldom be as simple, as those assumed and the results would have to be modified accordingly. If automatic voltage regulators are not installed, the generator reactance should be considered as line reactance, and if regulators are installed which increase the voltage with the load a larger value of reactance should be used in the "tie line" than would otherwise be desirable. Similarly, a smaller amount would probably be desirable in circuits feeding shunt synchronous converters and a larger amount should be installed in the case of over-compounded converters. Also, if the tie line is a short one where heating rather than the point at which the stations "drop out of step" limits the capacity, the reactance should preferably be much greater. Dr. Steinmetz has stated that it should be no less than two times the resistance, and apparently he refers to this case. The greater the reactance, the higher will be the power factor of the cross current, and so for this case a larger reactance can profitably be employed.

If line inductance alone is to be relied upon to give the necessary reactance, the wires should be spaced according to the curves shown in Figs. 2, 3 and 4. But in order to keep to practicable spacings, the sizes of conductors to be used are quite limited. Thus, for 60 cycles the range is from about No. 2 to No. 100, for 40 cycles from about No. 0 to No. 0000, and for 25 cycles from about No. 000 to 350,000 cir. mil.

Hence, it is seen why so little difficulty has been experienced in paralleling 60-cycle systems of moderate power over long distances, and also why it has frequently been impossible to operate similar 25-cycle systems in parallel without the installation of additional inductance.

NOTE 1. To find reactance which will give the maximum synchronizing power for small displacements:

Let $E_0 = e =$ Receiver voltage.

$I_0 = i + j\,i' =$ Line current.

$r - j\,x =$ Line impedance.

$E =$ Generator e.m.f.

$\phi =$ Phase displacement between generator and receiver voltages.

Then (neglecting the charging current)

$$E = E_0 + I_0\,(r - j\,x)$$
$$= e + i\,r + i'\,x + j(i'\,r - i\,x)$$

$$\tan\phi = \frac{i'\,r - i\,x}{e + i\,r + i'\,x}$$

If $E = E_0$ and the phase displacement is small, the following is approximately true:

$$i\,r = -i'\,x$$

$$\phi = \frac{i'\,r - i\,x}{e}$$

Hence

$$\phi = -\frac{\frac{i\,r^2}{x} + i\,x}{e}$$

If $W = ei$ = power delivered, then W/ϕ is a measure of the synchronizing power.

$$\frac{W}{\phi} = \frac{e^2}{x + \frac{r^2}{x}} = -\,e^2\frac{x}{r^2 + x^2}$$

To find the value of x which will make W/ϕ maximum, r being constant, we put

$$\frac{d\left(\frac{W}{\phi}\right)}{d\,x} = -\,e^2\frac{(r + x)\ (r - x)}{(r^2 + x^2)^2} = 0;$$

hence $x = r$.

NOTE 2. To find the reactance which will make the capacity of the line maximum when the generator and receiver voltages are constant but unequal.

Let e = Receiver voltage.
e_0 = Generator "
$\frac{e_0}{e} = a$
i = Energy component of current at receiving end.
i' = Wattless " " " " " "
ϕ = Angle between generator and receiver voltages.
r = Resistance of line.
x = Reactance of line.

Then from Fig. 5,

$$i\,r = e\,(a - \cos\phi)\cos\phi$$

The capacity of the line will be maximum when i is maximum. Hence, to find the phase displacement corresponding to this condition, we put $\frac{d\,i}{d\,\phi} = 0$

hence

$$\frac{d\,i}{d\,\phi} = \frac{e}{r}\,(2\cos\phi\sin\phi - a\sin\phi) = 0$$

$\cos\phi = \frac{a}{2}$ is the solution which makes the function maximum.

But from the figure $\phi = \tan^{-1} \frac{x}{r}$

hence

$$\frac{x}{r} = \sqrt{\left(\frac{2}{a}\right)^2 - 1}$$

A. S. McAllister (communicated after adjournment): Without attempting to criticise in any way the accuracy of the diagrams shown by the author in so far as they represent conditions assumed by him, attention should be called to a highly important feature ignored by him, which nullifies his conclusions that by proper proportioning the voltage of each unit by field adjustment it is possible to alter materially the sharing of load between generators operating in parallel. Quite independent of the electrical characteristics of circuits joining any two generators the actual load supplied by each generator to the electrical system—including its own circuits—depends solely upon the power delivered to the generator by its prime mover. This relation is fundamental, in that it is based on the law of conservation of energy—the one law the accuracy of which engineers have as yet not been bold enough to question. When two generators are operated in parallel or are connected to a common system, the division of the load carried by these two generators depends upon absolutely nothing other than the adjustment of the governors controlling the power supplied by the prime movers; it is not affected in any respect by voltage adjustment or resistance of the interconnecting circuits. The only effect that can be attributed to the resistance of the circuit interconnecting the two generators is that relating to the efficiency of the transmission. Of the total amount of power supplied by the two generators a part is dissipated in resistance of the interconnecting circuits, and this part may be supplied in whole or in part by one or the other of the generators, according to existing conditions, such as the relative voltages of the units; but the sum total of the power supplied by each generator is determined solely by the amount of power delivered to it by its prime mover.

In every case where a derived result is found to be contrary to the law of conservation of energy, it is safe to assume that at least one error has been introduced in the assumption or calculations. In the present case the author seems to have ignored the fact that the time-phase position between the voltages of the two generators in parallel and the currents in the system must at each adjustment be such as to allow each generator to supply to the system an amount of power equal to the amount delivered to it by its prime mover. All other quantities must adjust themselves to correspond to this one fundamental requirement.

DISCUSSION ON "SELF-STARTING SYNCHRONOUS MOTORS" (FECHHEIMER). PITTSBURGH, PA., APRIL 25, 1912. (SEE PROCEEDINGS FOR APRIL, 1912.)

(Subject to final revision for the Transactions.)

R. B. Williamson: Mr. Fechheimer's paper presents a large amount of interesting and valuable experimental data regarding a type of motor that is rapidly coming into use, and about which comparatively little has been published.

The self-starting synchronous motor, when started with the exciting field open-circuited, is essentially a squirrel cage induction motor for the time being, although it is a more or less imperfect one. In general, all the tests given, by the author point to the conclusion that the same rules laid down for the design of induction motors to secure the maximum starting torque with minimum line current, must also be observed in the design of a self-starting synchronous motor. For example, the reactances of both stator and rotor windings must be kept down as much as possible, and this in turn affects the number and proportions of stator and rotor slots. The squirrel cage winding must be designed with sufficient resistance to give the required starting torque, and the rotor bars must be spaced to avoid dead points as far as possible. This last point is very important. It is of little use to make elaborate calculations and go into refinements of design to obtain a squirrel cage which will produce a given *average* torque if the arrangement of bars is such that the *minimum* torque is insufficient to start the machine. The author has very properly called attention to this point. It is true that some of the requirements for a good induction motor cannot well be met in the synchronous motor, but the nearer the induction motor design can be approached the better, at least so far as starting is concerned. The large air gap and discontinuous rotor surface are desirable for the synchronous motor. So far as starting torque is concerned, the large air gap is not a great disadvantage; an induction motor may have a relatively large gap and yet be quite satisfactory so far as starting characteristics are concerned. It is true that the larger the gap, the larger will be the component of line current required for setting up the flux across the gap, and to this extent the total line current will be increased.

A point to be noted regarding the squirrel cage winding of a self-starting synchronous motor is that it is in use only during the starting period, except possibly for momentary or periodic currents that may flow in it if hunting takes place. The squirrel cage can therefore be designed with reference to the starting conditions rather than operating conditions. On the other hand, in a regular induction motor, working currents flow in the squirrel cage and the loss at starting must necessarily be limited in order to secure a satisfactory efficiency while the motor is running under regular load.

In designing the squirrel cage for a synchronous motor, the

service for which the motor is to be used should be kept in mind. For starting air compressors (unloaded), motor-generators or similar service, the torque required to overcome static friction is relatively high, but drops off rapidly as soon as the machine starts. At or near synchronism, the driving torque required is relatively small. For such service, a high-resistance squirrel cage is desirable, as it will develope a high torque at starting, and will allow the motor to come nearly up to synchronism on a half-voltage tap, on account of the light running load. There will not, therefore, be an excessive rush in current when the motor is thrown over to full line voltage. On the other hand, a motor used for starting, say, a centrifugal pump or fan, where the torque required to overcome static friction is not large, while the running torque near synchronism may be very high, requires a low-resistance squirrel cage in order to approach closely to synchronism before full line voltage is thrown on. It has been found that in case a motor is brought into synchronism on the low-voltage tap by the application of direct-current in the fields, it sometimes happens that when the motor is thrown over to full voltage, an excessive rush of current that may trip the circuit-breakers takes place. This can be avoided by increasing the field excitation to quite a large amount just before the switch is thrown over, thus increasing the counter e.m.f. of the motor. In case this is done, sufficient time must be allowed for the field current to increase to the required amount before throwing over to line voltage.

Mr. Fechheimer has called the attention to the falling off in torque near synchronism, and mentioned that the application of a small direct-current excitation will help the motor to pull in. The writer noted this effect some time ago, but the present paper is the first place where he has seen it pointed out that there is in each case a critical value for this excitation giving the best results. The curves shown in Fig. 11 are particularly interesting in this connection.

In applying direct-current excitation, care must be taken that it is not done when the machine is much below synchronism. Cases have occurred where this resulted in an insulation breakdown of the exciter armature on account of the high-induced voltage in the field of the synchronous motor when running with a large slip.

It is a well-known fact that synchronous motors, when started with the field circuit closed, frequently tend to stick at half speed. This, however, can hardly be attributed to higher harmonics in the wave form of the motor. For such to be the case, the harmonics would be of an even order, whereas even harmonics do not exist in a symmetrical wave. It seems that the phenomenon of running at half speed might be explained as follows: If an alternator of frequency n cycles per second is excited with direct-current, it must be driven at synchronous speed to generate this frequency. If, on the other hand, it is excited with alternating

current at frequency n instead of direct-current, and at the same time driven at synchronous speed, it will generate an e.m.f. having double frequency $2n$. Or, if it is driven at one-half synchronous speed and excited with alternating-current of frequency $\frac{1}{2}n$, it will generate normal frequency n. Now, if the latter case is reversed, and the generator operated as a synchronous motor at line frequency n, and if at the same time its fields are excited with alternating-current at frequency $\frac{1}{2}n$, the motor will run at one-half synchronous speed. When a synchronous motor is started with its fields closed and attains one-half speed, the frequency of the current in the closed rotor circuit is $\frac{1}{2}n$, and the effect is the same as if the motor were excited from an external source at one-half frequency. The motor, therefore, tends to lock into step and will so continue running unless the conditions are such that the torque due to the squirrel cage exceeds the pull-out torque of the synchronous motor when operating in this manner. When the field circuit is opened, the half-frequency exciting current disappears and the squirrel cage torque brings the motor nearly to synchronism.

Regarding the high e.m.f. induced in the fields at starting, particularly those wound for 250-volt excitation, this can usually be taken care of by extra insulation on the coils and collector rings. It should be remembered, however, that the same precautions regarding insulation should also be taken in connection with the wiring for supplying the exciting current. Mention has been made of the effect of solid poles in reducing the voltage generated in the field. Laminated poles without dampers or squirrel cage winding undoubtedly permit a high induced voltage but this is very greatly reduced in machines provided with a squirrel cage, so that the solid pole has little advantage in this respect. In one case with which the writer is familiar, the addition of dampers reduced the induced voltage to approximately 25 per cent of its former voltage.

The analytical discussion is of value in that it shows the relative importance of the various quantities entering into the determination of a given torque and the corresponding line current, power factor, etc., during the starting period. However, the whole subject is complex, and so many assumptions have to be made on which to base calculations, that the engineer must place reliance on tests more than anything else.

F. D. Newbury: The Institute is to be congratulated on having a paper of this quality on a design subject. We do not often get them. This is a very complicated subject. The synchronous motor is such a rapid-change artist during starting, starting as an induction motor, sometimes changing to a synchronous motor at half speed, and sometimes not changing until it gets pretty near the full speed, that the conditions are quite complex. I will not attempt any general discussion of Mr. Fechheimer's paper, but I do want to call attention to one or two points.

The "non-uniformity of torque at the instant of starting," and the "unbalance in phases," I have noticed is very much larger without amortisseur windings or without continuous end rings, when there are damper windings upon the individual poles. I do not believe Mr. Fechheimer mentions whether the motors he tested had continuous end rings or not.

In connection with the field circuit at starting, with an open field circuit, as Mr. Fechheimer points out, there is a large voltage induced in the field windings, particularly with the higher exciting voltages. He also points out that there is considerable decrease in starting torque with the field short-circuited, but the curves also show that with some resistance in the field circuit this decrease in torque is practically nil. I think it is, therefore, preferable to start the motors with the field circuit closed, and through as much resistance as is ordinarily placed in the field rheostat. This reduces, in fact, eliminates, the danger of any insulation strains in the field circuit, and does not cause any great decrease in starting torque.

Mr. Fechheimer devotes one section to the subject of "driving of fans and pumps." I am familiar with a motor of about 200 kv-a. at 500 rev. per min. on 25 cycles, which is arranged to drive a fan in which the starting conditions are very severe. The motor, must be placed on the line, with about 80 per cent of full load torque, at the instant of falling into step, with not more than 2.5 normal kv-a. from the line. I think that is about as good as a corresponding induction motor could do, which also bears out well the contention which has been made, that there is not a great deal of difference between a properly designed synchronous motor and a corresponding induction motor.

I agree with Mr. Fechheimer, that in obtaining good starting conditions, the distribution of slots in the rotor and in the stator, is important and that it is not good engineering to decrease the air gap in order to get a little better starting conditions. The decrease of air gap of course results in much smaller pull-out as a synchronous motor, and the pull-out as a synchronous motor is undoubtedly much more important than the slightly smaller starting current.

Mr. Fechheimer has devoted most of his paper to the conditions of actual starting. There is an equally interesting field for discussion—the conditions after the motor is connected to the low voltage, and the starting operation is completed by connecting to the line voltage and exciting the field.

As Mr. Williamson pointed out, the complete starting conditions are improved with an increased field current. The armature current on low voltage may be considerably higher than it would be with lower field current but in throwing over to line voltage, there is not an excessive rush of current which will open the current breakers.

H. M. Gassman: The mention of induced voltage in the fields of synchronous motors recalls some comparative tests I made on

synchronous motors with 250-volt windings. The motors were 250 kv-a. capacity and the voltage was measured at the field switch on the switchboard. In both cases approximately one-half normal voltage was applied for starting the motors.

The solid-pole motor gave as a maximum 1500 volts induced in the field at starting. The motor with laminated pole and copper end rings showed an induced voltage of 4000. Such induced voltage deserves consideration on account of the danger to which the operator is exposed when starting synchronous motors and the chance of such induced voltage breaking down the ordinary insulation used on the complete field circuit and even breaking down the rotor insulation after it has deteriorated from use or exposure. The rotors in this case were designed to withstand 5,000 volts when new, which leaves a very small factor of safety for deterioration when the induced voltage is so high.

When the ammeter of the synchronous motor is not short-circuited in starting, it is an advantage to insert the resistance in the field, as suggested by Mr. Fechheimer, for the purpose of reducing the chances of damaging the ammeter needle. Damage to the needle might be avoided by selecting an instrument with larger capacity and also an increase in the size of the current transformer. This, however, is not desirable on account of the performance of wattmeters and the indicating meters on light loads.

A. M. Dudley: One point in Mr. Fechheimer's abstract of his paper must be taken with certain modifications and also brings out the need for correction in one of our existing Standardization Rules. I understand that such correction is contemplated in connection with the revision now under way. I refer to Mr. Fechheimer's statement that the real watts input into the rotor is a fair measure of the starting torque. This statement is reasonably correct but he said, in addition, that if the real watts input into the primary at standstill were measured and the loss in primary copper were subtracted therefrom, the remainder would reasonably represent the input into the rotor which reappears directly as starting torque. It is well known at the present time that there are certain losses at standstill due to eddy currents in different parts of the machine, which do not appear as starting torque and which are not present as losses when the machine is running at normal full load speed. For this reason the starting torque as figured in this manner from the locked kilowatts input is usually higher than the machine actually develops and the secondary copper loss as so figured is too high showing an efficiency at full load speed which is less than is actually the case. This discrepancy is not always so small as to be negligible and in extreme cases a starting torque of 1.7 times full load torque may be indicated from the locked kilowatts and the machine may actually test out only 1.2 times.

Referring to the Standardization Rules on this point, under Section 167, they definitely state that the locked watts when the

full load primary energy current is flowing in the windings are directly chargeable against the motors either as copper losses in the primary and secondary or as so-called load losses. This, I believe, we all recognize as incorrect and the rules could be modified so as to correct this inaccuracy.

W. J. Foster: I would like to say a word with reference to the solid pole versus the laminated pole. I agree that it is not permissible to have such high induced potential as mentioned in a particular case by a previous speaker. Of course, in the designing of the synchronous motor we must strike a compromise. There are a good many conflicting factors, and we must combine them so as to obtain a motor that is practicable.

Now in the case mentioned of the motor with solid poles, undoubtedly the reduction of the induced voltage, due to the solid pole, is a good thing, when you consider the danger of the induced potential. We ought not to allow a synchronous motor to be built that is absolutely open-circuited and with laminated poles and nothing to keep down the induced potential. In the particular motor that the speaker had in mind as subject to criticism, probably the squirrel cage winding, there is very high resistance. There has been that danger in the past. Many motors have been built with altogether too high a resistance. Such a motor shows up well in the initial start, since it keeps down the amount of current taken from the line, and if the question is asked as to the current required to start, the answer is made so as to apply at the instant of starting. Hence there is the temptation to make that very low, say, full load current or less than full load current. This proportioning of squirrel cage windings does not result in a machine which it seems to me is a practicable one—either the windings should have much lower resistance, or, what is simpler, short-circuiting collars should be put on the poles, as they will cut down the induced potential. I recall some experiences in the matter of short-circuiting collars. There is danger of getting too low resistance, so that there will be trouble at the half-speed point in starting up. There is danger, if alloys are called for, on account of the uncertain character of what one gets from the foundry. You sometimes get material with 50 per cent higher resistance than at other times.

In general it is better to design the squirrel cage windings with lower resistance or with that which it needs as it approaches synchronism.

I agree with the emphasis laid by the author on the desirability of providing definite paths for the current in the starting winding. It seems to me more scientific and approaches more nearly the induction motor design. The synchronous motor is at a disadvantage when compared with the induction motor, since no serious attempt has been made to develop synchronous motors as a class of machines by themselves. Most commercial synchronous motors are generators adapted to the use as motors.

The author brought out a number of points with which I agree

As to the matter of air gap,—when you consider all the characteristics of a good motor, I think the gap of a synchronous motor should be approximately the same as of a generator.

I would like to ask Mr. Fechheimer, in closing, if he is ready to make a statement with reference to the ratio of slots, the region within which he considers good practice to lie? Mr. Fechheimer has warned us both in directions, against the multiple and against the prime relation, this helps a good deal, but I should like him to make a positive statement. I think we are all greatly indebted to Mr. Fechheimer for the paper, which is an excellent treatise on the subject.

B. G. Lamme: Considering the synchronous motor problem as a whole, it has been known for many years that, in starting and accelerating such a machine, it is an induction motor until it comes up to synchronism, and that, while acting as an induction motor, it followed the laws of the induction motor; or rather that it followed these laws as closely as the crudeness of the construction would permit, for the synchronous motor is naturally an imperfect form of induction motor. It has been known for a long time that the starting torque of the synchronous motor varies as the square of the impressed voltage, which is a well known law of the induction motor. The same is true of many other relationships which Mr. Fechheimer has brought out, and the great value of his paper lies in the fact that he has shown how very closely the synchronous motor follows the same laws as the induction motor, when its imperfect construction as an induction motor is taken into account.

One of the first things which we teach designers of induction motors is that, to obtain full load torque at the start, there must be an expenditure of at least full load energy in the secondary circuit. Mr. Fechheimer shows that in the synchronous motor we get practically the same result in spite of the fact that the field structure of the synchronous motor, which becomes the secondary of the machine as an induction motor, is, magnetically, badly proportioned, compared with the usual secondary construction of the normal induction motor. At half speed the synchronous motor tends to hesitate, one might say, or to drop into a sub-synchronous speed. In this feature it also follows the principles of the induction motor which, with a wound secondary, will tend to run at half speed when its secondary has only one circuit or phase closed on itself, and will even pull a considerable load. The synchronous motor at half speed represents a similar condition to a certain extent. The secondary conditions, represented by the polar arrangement of the magnetic circuit and the field coils of the synchronous motor, tend to give, to a certain extent, a single-phase condition in the secondary. In particular, the field winding, closed on itself, tends to give the effect of a single secondary circuit, and therefore tends to lock the machine at half speed. This action is neutralized, to a certain extent, by any polyphase actions in the secondary

circuit and the greater the polyphase tendency compared with the single-phase, the less difficulty there is in carrying the machine past the half-speed point. If the single-phase action of the secondary preponderates, the motor may have a strong tendency to lock at half speed.

When the motor speeds up, it approaches as near synchronism as the resistance of the secondary winding will allow. With a very low-resistance secondary winding, a very close approach to synchronism is attained, as in the induction motor, and it is easier to pull the machine into step. The higher the resistance of the secondary, and therefore the better the starting conditions, the greater will be the " slip " at full speed, and therefore the harder will it be to pull the motor into synchronism. It is difficult to "see" just what is going on in the motor at the instant it pulls into synchronism, but the conditions can be approximated by considering the synchronous motor at standstill with its terminals connected to an alternating-current generator which is started from rest, the fields of both the generator and motor being excited by direct current. At the first instant of movement of the generator, there can be no current between the machines, because there is no electromotive force generated until the generator gets into motion. A certain low speed is required to generate enough e.m.f. to overcome the resistance of the armature windings of the two machines. At one per cent of normal speed there may be sufficient current flowing between the machines to exert a considerable torque, but the motor is at standstill while the generator is rotating at one per cent of normal speed. Observing the rotor of the synchronous machine under this condition, it will be seen to quiver or oscillate back and forth a few times, and then jerk or swing itself into step. Sometimes there is simply a small quiver and then a sudden jerk into synchronism with the generator. At other times, there may be a very pronounced oscillation or swing of the synchronous motor, and finally it swings itself to such an angle that it naturally falls into step. It is obvious that the nearer the generator can be to zero speed when this action occurs, the easier it will be to pull the synchronous motor into step. Watching a motor start under these conditions gives a very good impression of what happens under ordinary conditions of synchronizing when the generator is running at normal speed.

In one important feature the synchronous motor is quite different from the induction motor. In the synchronous motor, in order to get a good pull-out torque, usually the direct-current field magnetomotive force must be high compared with the armature magnetomotive force. Ordinarily, the field ampere-turns in the synchronous motor will be about one and one-half times as great as the effective armature ampere-turns at full load, in order that the motor may be able to develop a maximum of about two times full load torque. This high field strength is

necessary in order to give the proper overload torque. On the other hand, in the induction motor the magnetizing ampere-turns are possibly only 30 per cent of the full load ampere-turns; that is, in the induction motor, the exciting ampere-turns are only about 20 per cent as great as in the synchronous motor. Herein is one prominent difference between the two types, and in this lies the difficulty in making a machine which will be both a good synchronous motor and a good induction motor. If the induction motor requires only 30 per cent of full load ampere-turns to excite its field, then as a synchronous motor it would still require only an excitation corresponding to 30 per cent of the armature ampere-turns, whereas, in fact, it should have about one and one-half times the armature ampere-turns for excitation, as stated before. With 30 per cent excitation, it would have a pull-out torque of possibly 40 per cent of full load torque, as a synchronous machine, which is an impracticable condition. In order to get two times full load torque it would require an excitation of one and one-half times the ampere-turns of the armature, as stated before, and when acting as an induction motor the same excitation would be required. This would therefore lead to an induction motor having a magnetizing current of one and one-half times the value of the work current, which would mean a power factor of less than 50 per cent. This, therefore, indicates the impracticability of making a good synchronous motor which is able to drop out of step and operate as a good induction motor. The two conditions are conflicting, when running conditions are taken into account. A good synchronous motor therefore will not make a good induction motor, when carrying load.

Francis B. Crocker: I do not think there is time, when we have such an important and difficult paper to discuss, to defend the Standardization Rules, but there is opportunity, I believe, at the present time, to say that the Standardization Rules Committee is in existence, and that this committee is considering the revision of the rules, and any points of that kind which need consideration or revision should be presented to the committee.

I think also that the Standardization Rules should be revised from time to time. What may now be the actual wording of them may require modification as greater knowledge and change of practise takes place. In fact, I think it would be very extraordinary, and perhaps very undesirable, if they should remain unchanged, and not be revised from time to time. They have already been completely revised twice since their inception, and several other important changes and additions have been made when they were needed.

I think the point that Mr. Lamme has just spoken of is a thing we should bear in mind. Two machines, the synchronous motor and the induction motor, are shown to be more alike than we have previously considered, having been regarded, in fact, as quite different. After all, they are quite alike, and, of

course, the same laws necessarily apply to both, but, unfortunately, it does not seem to be possible to make a compromise machine which would have the advantages of the induction motor in starting up, and the advantages of the synchronous motor in being able to have leading current and improve the power factor of the other apparatus. If such a result could be obtained, there would be a great field for a motor which would have the advantages of both.

C. P. Steinmetz: Mr. Fechheimer's very valuable paper is especially interesting to me, as I always had a very strong predilection for the synchronous motor, especially its larger sizes, since I consider this type of alternating-current motor as decidedly superior in its electrical characteristics, in its reaction on the electrical system, and more particularly with regard to power factor and voltage regulation. The synchronous motor does not spoil the power factor, but can operate at unity power factor, or can be used to improve the power factor spoiled by other apparatus.

The synchronous motor gives a fixed voltage point determined by its direct-current excitation, and thereby is able to, and does, hold up the voltage or pull down the voltage, depending on the conditions of the system, and thereby can be used to, and does, control the voltage of the system, especially in long-distance power transmission, where voltage regulation is more difficult. This is a very important characteristic, as the experience on the Pacific Slope since the early days seems to have shown.

The synchronous motor has no starting torque, as such. It starts as an induction motor. It has not always been realized, especially with the squirrel cage synchronous motor, that is a synchronous motor provided with the amortisseur winding, how large a starting torque you can get from it, and it is not completely realized today. When we first considered the introduction of the squirrel cage pole face winding in the synchronous motor, to give it powerful starting characteristics, we made a number of investigations which were rather startling. With a standard alternating-current generator of moderate size, provided with squirrel cage windings, we determined the torque characteristics from standstill to synchronism, and found that the maximum torque of the machine as an induction machine was materially higher than the maximum torque of the same machine as a synchronous motor at unity power factor, with the same terminal voltage applied.

That means you can provide any desired starting torque in the synchronous motor. In giving the powerful starting torque to the synchronous motor by means of the squirrel cage winding or amortisseur winding we naturally meet with the same difficulty we meet with in the induction motor, that the requirements at standstill and requirements at speed are opposed to each other. High torque at standstill requires fairly high secondary resistance. To bring high torque up

close to synchronism requires very low squirrel cage resistance. Now, in the synchronous motor, it is not merely sufficient to start from rest and run up to some speed, but we must run up so close to synchronism that the motor can pull into synchronism, into step, that is, we must go to a fairly low slip. The ability of the machine to pull into synchronism depends on the slip and therefore the resistance of the squirrel cage and on the momentum of the moving masses, and also it depends very essentially on the mechanical configuration of the stator and rotor, as you can easily see by considering a machine with uniform reluctance all around, like a standard induction motor. Such a machine, without direct-current field excitation could never pull into synchronism, and with the direct-current field excitation it is less able to pull into step than a machine with definite polar projection, and in the latter we naturally also find very wide differences, depending on the configuration of the polar structure of the machine.

In the early days of the synchronous motor, twenty years ago, when we built the first of these machines, we were very much afraid of the machines not being able to start off, and we provided three-phase bar windings in the field poles, brought out to a switch, to be able to insert resistances in starting, and afterwards to short-circuit them. Fortunately, experience showed that such complication was not necessary, and it was very soon abandoned. However, it would be extremely desirable if we could design the squirrel cage windings of the synchronous motor, and probably also of the induction motor, so that their resistance would automatically vary to suit the conditions, from high resistance at standstill to very low resistance at speed.

Mr. Fechheimer mentioned the question of the short air gap. In the induction motor start of the synchronous motor, a short air gap is advantageous within certain limits, just as within other limits a short air gap is advantageous with the synchronous motor, but when you consider a still further decrease of the air gap, you reach a point where a further reduction of the air gap becomes objectionable in the starting of the synchronous machine as an induction motor, where we lose again by further reduction of the air gap. Decreasing the air gap, with the same size and relative position of stator and rotor slots, etc., at the same volt-ampere input, the average starting torque increases, but finally it increases very little. At the same time the irregularity of the starting torque increases, that is, the uniformity of the torque in different positions decreases.

What counts in the starting of the machine is not the average starting torque, but the minimum starting torque, the starting torque in the minimum torque position, and this depends on the relative proportions of air gap and width of slot, and also on the relative number of stator and rotor slots.

To get a reasonably uniform torque with a small air gap means very many narrow slots, which is uneconomical in general

in the synchronous motor, and impracticable in a high-voltage machine, but with such a reasonable number of stator and rotor slots as are economical, and even as are permissible, in the synchronous motor, there is a limit in the air gap below which you cannot go without impairing the starting of the machine as an induction motor, by decreasing the torque in the minimum torque position.

We usually think of a large air gap as producing a high exciting current, and so it does in the induction motor, but the high exciting current counts in proportion to the total current. An induction machine would be inoperative if the magnetizing current were 200 per cent of full load current. In the induction motor starting of the synchronous motor such a magnetizing current of 200 per cent is unappreciable, if you consider the synchronous machine starting by auto-transformer at half terminal voltage, twice full load current, which means taking from the line only full load volt-amperes; 200 per cent magnetizing current, referred to half voltage and double current, is only 50 per cent, and would thereby increase the total current only very little.

If, instead of allowing a nominal 200 per cent exciting current, you would go down to as low an exciting current as is the limit in the poor induction motor, or 50 per cent, the increase of irregularity of the starting torque would be very much greater than the percentage decrease in the total of current, and therefore to get a minimum starting torque equal to that which you get with the bigger air gap, you would have to greatly increase the volt-ampere consumption. Thus it would be an engineering mistake to reduce the air gap still further.

You see that the conditions in the starting of the synchronous motor are different with regard to magnetizing current, from what they are in the running of the induction motor and economical proportioning requires a larger air gap in the synchronous motor starting than in the induction motor operation although there is naturally a limit in the size of the air gap, beyond which it is uneconomical to go.

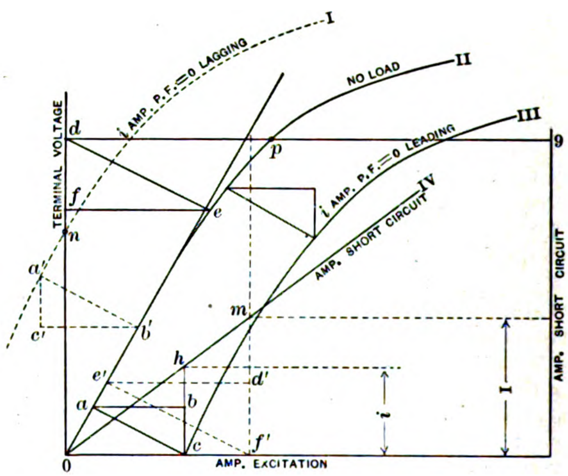
The last point which I desire to make has reference to Standardization Rules. I would like to say here to you what I have said before: There is no use in kicking against the Standardization Rules or objecting to them. Instead of saying that such and such a rule is unsatisfactory and should be changed, say how it should be changed, and give the evidence proving your contention, formulate a better rule and you will find that Mr. Lamme and myself, who have the very questionable pleasure of providing for the changes, will be delighted to act upon your suggestion. But a mere statement that the rules are not satisfactory, means nothing, and we cannot act on such a statement until something better is offered.

We know that things had to be put in the rules, as representing the best that could be obtained with the limited experience and

knowledge had of certain subjects. Now, what we want is to be provided with the data by which we can correct any existing rules that are not satisfactory, and we shall be delighted to do so, but, as I say, a mere objection to the rules means nothing. We know ourselves that many things should be changed, and the only question is how to change them and prove how the change should be made.

Bradley T. McCormick (by letter): During the period of starting, the self-starting synchronous motor acts as an induction motor of special type, but when synchronous speed is obtained, the machine operates as a synchronous motor under the special condition of no excitation, until the field circuit is closed.

While the starting characteristics of the self-starting synchronous motor, before it has reached synchronous speed, can only be determined by methods which are more or less empirical,



the current input to the motor after it has reached synchronous speed but before the fields are excited, can be accurately determined. Although this current is less than the starting current at rest, it is still of some interest, as it represents one of the points on the current-speed curve which can be determined easily and with accuracy.

In the figure presented herewith, curve II shows the no-load saturation curve of a synchronous motor, while curve III shows the saturation curve at a leading power factor of zero, with the full load current of *i* amperes per phase. Curve III is the path traced by the point *c*, as the triangle *abc* moves upwards in such a manner that point *a* follows curve II. The line *ab* is the armature reaction expressed in terms of amperes excitation, and *bc* is the reactance drop of the stator in volts.

Curve I is the full load saturation curve for zero power factor lagging, and is obtained by turning the triangle *abc* into the position *a′b′c′*, and moving along curve II as before.

The point *n*, where curve I crosses the axis of ordinates, locates the terminal voltage at which the motor will draw full load current when running at synchronous speed without excitation. In order to find the current drawn on full voltage *od*, draw *de* parallel to *ac* and construct the traingle *efd* similar to *abc*. The required current can either be found from the relation

$$I = i\,\frac{f\,e}{a\,b}$$

or by transposing the triangle into the position *e′f′d′* and taking the current from the short-circuit curve at the point *m* directly above. Were it not for the saturation of the iron, which causes the no-load saturation curve to deviate from a straight line, the perpendicular lines through *f′d′* would cut the no-load saturation at the point *p*.

The above treatment can therefore be simplified into the following simple rule:

Neglecting the saturation of the magnetic circuit, a synchronous motor running on any voltage at synchronous speed without excitation, will take from the line a current equal to the short-circuit when run as a generator with the fields excited to a value corresponding to the above mentioned open-circuit voltage.

The copper loss of a squirrel cage winding of a self-starting synchronous motor can be calculated by the same method as that employed for induction motors. The following formula I have used with good success for induction motors, and although it does not go into the refinements to the extent of Mr. Fechheimer's formula, it gives results whose accuracy falls within the variation of the resistance of the composition metal in the end rings.

Squirrel cage copper loss

$$= \left[\left(\frac{s}{\pi}\right)^2 2\,R_r + R_b\,s\,p\right] I_b^2$$

I_b = the current per rotor bar.
R_b = the resistance of one rotor bar.
s = the number of rotor bars per pole.
p = the number of poles.
R_r = the resistance of one end ring measured clear around its circumference.

C. J. Fechheimer: It is indeed gratifying to me to have heard from so many prominent engineers that most of the conclusions at which I arrived in my paper are in accordance with their own

views. I was to some extent expecting opposition to a number of my conclusions, especially in reference to the size of air gap and the good results which it is possible to obtain with the synchronous motor at starting as compared to the squirrel-cage induction motor.

Mr. Williamson speaks of the prevention of the current rush accompanying the throwing over to full voltage when the fields are excited with direct current. The method which I favor consists in keeping the stator circuit closed and at the same time in having sufficient current in the fields of the motor to enable the power factor to come approximately to unity when throwing on the higher voltage. In this way the current is reduced rather than increased.

The explanation offered by Messrs. Williamson and Lamme of the tendency to refuse to accelerate beyond half speed when the field circuit is closed upon itself, I believe accounts for the phenomenon better than the theory I advanced. After more mature consideration, I am quite willing to agree with these gentlemen that this tendency is due not to higher harmonics, but rather to the single-phase reaction of the rotor upon the polyphase stator.

In regard to Mr. Newbury's question in reference to the rotor construction of the motors which were tested, I would inform him that the solid pole rotors were not provided with any kind of squirrel-cage winding; only those curves shown in Figs. 7 and 8 pertain to motors with amortisseur windings, the construction consisting of bars in the poles which were connected at the ends with continuous rings. Figs. 7, 8 and 9 refer to the same motor, the amortisseur windings have been removed in tests plotted in Fig. 9.

In general, I do not think it advisable to connect the field rheostat in series with the rotor at starting. It is possible that the motor Mr. Newbury has in mind is different from those I am familiar with. It is seldom that the field rheostat has a resistance more than four times that of the field. In order to obtain more favorable starting conditions the resistance in the field circuit should be approximately equal to the reactance thereof. Usually the reactance is more than one hundred times the resistance. Hence, with the rheostat in series, the resistance in the field circuit would be approximately equivalent to one-twentieth of the reactance. Therefore, this resistance is entirely too small to secure small line current for a given torque. The unfavorable results obtained by short-circuiting the fields or by having a comparatively small resistance in series with them, is, as one would suppose, less marked when the amortisseur winding is present than when it is removed. This can be seen by a study of Figs. 3, 4, 7, 8 and 9.

It would seem that Mr. Newbury has achieved remarkably good results in the 200-kv-a. synchronous motors, and this would tend to bear out more fully the statements that have been made

by others contributing to this discussion, that the synchronous motor, when properly and carefully proportioned for starting conditions, can be made comparable to the squirrel-cage induction motor.

In regard to Mr. Dudley's statement to the effect that all of the losses in the rotor are not necessarily productive of torque at the instant of breaking loose from rest, I would refer him to item 7 in the paper under "Determination of Starting Characteristics with Laminated Poles and Amortisseur Winding" as follows: "Losses due to a pulsating component of flux not productive of torque." This I believe covers the condition which Mr. Dudley pointed out. In this connection, however, I would call attention to the inaccuracy of commercial starting tests. When an error from tests is as great as Mr. Dudley describes, it is usually due to the pronounced effect of bearing friction, to overcome which a considerable portion of the developed torque is required.

There is no doubt that the high potential induced in the rotor circuit is undesirable. From comparisons which I have made between solid and laminated pole machines, I am inclined to believe that solid pole machines give rise to lower induced potential than those with laminated poles. As Mr. Foster says, however, much depends upon the resistance of the amortisseur winding. For a given flux entering the pole heads the induced potential in the rotor coils is decreased as the resistance of the amortisseur winding is lowered. There is, however, this disadvantage—the line current drawn for a given starting torque is materially increased, and the starting torque for a given impressed electromotive force on the stator terminals reduced, by the low resistance squirrel-cage winding. On the other hand, if a carefully proportioned high-resistance amortisseur winding is used, less flux and less stator potential is required for a given starting torque, and with this lower flux I do not believe a prohibitively large potential is induced in the rotor coils. Comparisons I have made lead me to believe that the induced potential for *a given starting torque* with a high-resistance squirrel-cage winding is not very different from that with a low resistance winding. On the other hand, however, with solid poles, the induced potential in the rotor coils is much lower than with a high-resistance or even low-resistance squirrel-cage winding when the poles are laminated, due, of course, to the skin effect; at the same time the currents are crowded into such a thin shell that the torque is increased rather than decreased.

As Mr. Foster reminds me, the statement which I made in my paper in respect to the number of slots in the rotor as being dependent upon the judgment of the designer, is somewhat vague. If the motor is to be directly coupled to an unloaded, reciprocating air compressor, the starting torque should be greater than the torque during acceleration. In such cases, therefore, a high-resistance winding is desirable. The variation of starting

torque for different positions of the rotor when the number of rotor slots is an exact multiple of those in the stator is very much less with a high-resistance squirrel-cage winding than with one of low resistance. Hence, when starting air compressors with the high-resistance winding, it should be satisfactory to pitch the rotor slots a multiple of the stator slot pitch. On the other hand if the motor is to be directly coupled to a centrifugal pump which is usually high-speed, the pole pitch will be large and the air gap long. We can, in general, apply the same rules to the losses in the squirrel-cage winding when operating at synchronous speed if the rotor slot pitch is not a multiple of the stator slot pitch, as apply to solid poles and open slots. By making the slot pitches in the stator and rotor small enough we can effectively eliminate eddy current loss when the large air gap is taken into consideration. When driving centrifugal pumps the high torque is needed just below synchronism, hence a low-resistance winding should be used to make the slip as small as possible. This, then, implies that the pitch of rotor slots should be other than a multiple of the stator slot pitch. In a similar way each case can be decided upon its own merits, in the same manner in which the designing engineer is called upon to use his judgment in proportioning other parts of the apparatus.

As Mr. Lamme says, it is a little difficult to understand why the synchronous motor pulls into synchronism instead of "slipping" as is the case with induction motors. Also, as Dr. Steinmetz states, the motor would not pull into synchronism without direct current in the field coils were it not for the peculiar configuration of the rotor. I have usually compared this phenomenon with the tendency of the shuttle-wound armature used in magnetos to fall into line with the permanent poles. This, of course follows the fundamental laws and conceptions of the magnetic field. With the distributed winding type without definite poles, there would be no tendency to lock into synchronism unless direct current were applied to the field coil. With definite poles, as is illustrated by the tests given in the paper, when the rotor is near synchronism the "pull-in" effect is more pronounced due to the poles being more clearly defined. In the definite pole machine at synchronous speed without direct current in the field coils, the excitation is produced by currents in the stator which set up a field revolving at synchronous speed. Neglecting power factor, qualitatively but not quantitatively, the same effect is produced as with direct current in the field coils.

Mr. Lamme has compared the excitation of the induction motor to that of the synchronous motor. The question naturally arises: why do we have to supply so many more ampere-turns in the synchronous motor than we do in the induction motor? The answer of course is: We must take up these ampere-turns in various parts of the magnetic circuit to prevent the motor from falling out of step when the load is placed upon it. In

other words, approximately five times as much magnetomotive force is required to hold the rotor in synchronism as would be the case with a certain "slippage."

This brings up another interesting question: why cannot a phase-wound rotor, star-connected, be used to advantage in a synchronous motor if all of the rotor winding is employed in the ordinary way for starting and two legs of the star be excited with direct current for synchronous operation? We could of course, use a large air gap, for, as has been pointed out, the large air gap is not a bad feature as regards starting. With the rotor construction ordinarily used in synchronous motors—motors with definite poles and edge-wound single layer fields—we have the ideal conditions for cool operation. On the other hand, with a phase-wound rotor construction we are extremely limited in space and unless the motor be made very large, it would be difficult to get sufficient ampere-turns in the rotor for leading power factor, or in many cases for unity power factor, to provide a liberal pull-out torque, unless prohibitively high temperatures are obtained. In other words, a good induction motor will not make a good synchronous motor.

Dr. Steinmetz calls attention to the valuable characteristics of the synchronous motor in that it can be used to great advantage for voltage regulation, and at the same time can pull a mechanical load. It is for this reason that the tendency is toward using the synchronous motor in preference to the induction motor. This is also true where slow-speed motors are required, such as are used for driving reciprocating air compressors. The speed is then so low that the induction motor has extremely poor power factor, whereas the synchronous motor can be used to advantage to improve the power factor of the system. Were we compelled to resort to the use of an auxiliary device for starting such apparatus, it would not come into use to nearly so great an extent as with self-starting motors.

The method which Mr. McCormick has proposed for predicting the amount of current which would flow when the motor is in synchronism and without direct-current excitation, depends upon a number of approximations. As this current usually flows for a short interval, it is seldom important that it be predicted with great accuracy, and hence approximations which appear in Mr. McCormick's method should give sufficiently accurate results for commerical purposes. This brings up another interesting point in connection with the size of air gap previously referred to. When operating at synchronous speed without direct-current excitation, the current drawn from the line depends almost wholly upon the magnetomotive force required to force the flux across the air gap. This current can be greatly reduced by exciting with direct current while operating on fractional voltage, as has been stated.

The formula which Mr. McCormick has given for calculating losses in the conducting circuit of squirrel-cage induction motors is similar to that which I have used. It depends upon a sinusoidal space distribution of flux. I do not think that we could apply this formula to the case of a synchronous motor in which the distribution of flux is so far from being sinusoidal due to the peculiar rotor configuration.

Discussion on "Air Gap Flux Distribution in Direct-Current Machines" (Moore), Portland, Ore., April 18, 1912. (See Proceedings for March, 1912).

(Subject to final revision for the Transactions.)

H. Weichsel: The method used by Mr. Moore for investigating the actual flux distribution in a direct-current machine consists in determining by means of an oscillograph the wave shape of the alternating e.m.f. generated in an armature coil spanning 180 electrical degrees. The assumption is then made that the field distribution is similar to the wave shape of the generated e.m.f., providing we consider that the base line of the half wave is equal to the pole pitch of the machine. This assumption leads to correct results if the field distribution is absolutely constant and does not change with time. If, however,

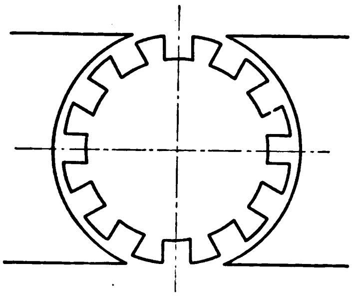


Fig. 1

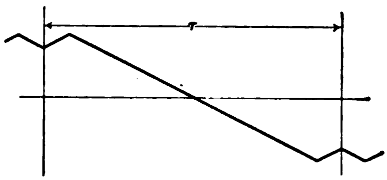


Fig. 4

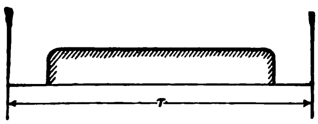


Fig. 3

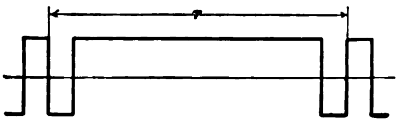


Fig. 5

the field distribution or the field strength changes with time this method must lead to incorrect results.

In a direct-current machine with an unslotted armature it is true that the field distribution is independent of time, and the above method will give correct results. If, however, the armature is slotted it is evident that the field distribution changes with time because the teeth have a tendency to drag the flux in the direction of rotation.

In Fig. 1 a two-pole machine with 12 armature slots is shown and in the following discussion we will assume that the machine has no fringing. The field distribution over the armature surface at the moment that a slot center coincides with the center line of the pole may be represented by Fig. 2*a*. Likewise Fig. 2*b*, 2*c*, etc. represent the field distribution over the armature surface after the armature has moved a distance equal to

$p/8$; $2p/8$, etc., where p equals the tooth pitch. The average field strength for a certain point on the armature circumference can therefor be obtained by finding the average of all the above ordinates for the point under consideration. By computing this for a series of points the average field distribution in space over the whole armature surface has been obtained as shown in Fig. 3.

Mr. Moore makes the assumption that the wave shape of the e.m.f. coincides with this field distribution.

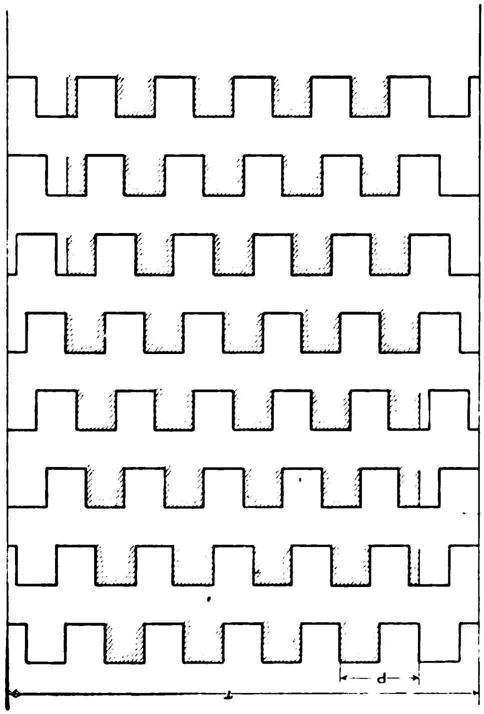


FIG. 2

It is an easy matter to predetermine the wave shape of the e.m.f. by the fundamental induction law:

$$E = \frac{d\,N}{d\,t} . s$$

Where N represents the lines penetrating the coil with s turns. Therefore if we plot a curve with the total lines penetrating the search coil as a function of time (assuming constant velocity of armature) we can obtain the e.m.f. generated at any given

instant by drawing the tangent to the curve at that point. Fig. 4 shows the total lines interlinked with the search coil plotted as a function of time as found by the use of Fig. 2. Fig. 5 is the e.m.f. curve obtained by plotting the values of the tangents to the curve shown in Fig. 4. A comparison of Fig. 5 and Fig. 3 shows at a glance that these two curves are entirely different. The assumption that the wave shape of the generated e.m.f. represents the average field distribution on the armature is therefore not correct for the case in which the armature field changes its shape with time.

The conclusions drawn in Mr. Moore's paper will, however, be correct in general because owing to the fringing of the lines, the field does not change very materially with time; but I believe great care must be exercised in trying to analyze the meaning of small ripples in the oscillogram as has been attempted in Mr. Moore's paper.

DISCUSSION ON "PRACTICAL JOINT POLE CONSTRUCTION" (MACDONALD), PORTLAND, ORE., APRIL 18, 1912. (SEE PROCEEDINGS FOR MAY, 1912.)

(Subject to final revision for the Transactions.)

A. H. Griswold: I am personally familiar with the proposition which Mr. MacDonald has handled, and I desire to say that it is fully appreciated by the people of Los Angeles, as well as the operating companies.

The Pacific Telephone and Telegraph Company alone in Los Angeles owns, either solely or jointly, about 40,000 poles. When you consider that there are nine pole-using companies in Los Angeles, you can realize the relative magnitude of the problem on which Mr. MacDonald has been working.

The joint construction of pole lines provides a wonderful conservation of capital, and it has also done another thing which is of tremendous value. Public agitation on pole lines in connection with the beautifying of streets in the cities and towns is becoming greater every day, and it is only by a proper cooperation of the pole using companies in constructing joint pole leads that adverse public criticism may be alleviated, and requests for underground construction, which are often prohibitive from a cost standpoint, eliminated.

The slowness of pole-using companies in constructing joint pole lines has provoked so much public agitation that in some states laws are being considered, and recently in one state in the West a law was passed of such an arbitrary nature that to have effected a combination arrangement in accordance with the requirements of that law would have required in some cases 110 or 120 ft. poles. In other words, the requirements were absolutely absurd.

Now if the wire-using companies would cooperate and effect these combinations along good engineering lines, providing for the proper factors of safety, both to life and property, they would forestall much of the agitation, and many of the things that frequently prove oppressive and burdensome to the utility corporations.

I therefore believe that the joint pole question is a very live issue, and as engineers we should consider it very seriously.

There is one point in connection with the joint work that has not been touched upon. There has been no combination made that introduces any physical electrical hazard to any of the other wire using companies. The low tension wires, or signal wires, are never placed on the same pole, or the same side of the street with the high tension wires of a voltage beyond the limits of the protective devices of the low tension, or signal circuits. In Los Angeles the high tension combinations are made on one side of the street on one set of poles, and the low tension combinations on the other side of the street on another set of poles, and where crossings are necessary, they are effected in an approved manner.

L. B. Cramer: I would like to ask Mr. MacDonald if the telephone companies experience any trouble when their wires are placed on the same pole with lighting companies' primary lighting circuits or arc circuits.

Mr. MacDonald spoke of high tension wires not being allowed on the same poles with signal wires, at the same time I wondered if the classifications were such as not to be objectionable to the telephone companies from the standpoint of inductive disturbances.

I would also like to ask on what basis the division of shares or units in each pole is made. For example one company might want space for a 13,000 volt power circuit or a higher voltage power circuit, if such are allowed in the city; another company space for signal wires, telephone circuits, etc. The paper does not cover the division of ownership in each pole.

Gano Dunn: Mr. MacDonald has undoubtedly made out a perfectly conclusive case in favor of joint pole construction as practiced in Los Angeles. I am glad Mr. Griswold has contributed to the record certain statements with regard to the hazards, etc. he has just made. I may say the most beautiful pole construction I ever saw was in Los Angeles in this district when Mr. MacDonald and others took me before I came to Portland, so I can fully agree with Mr. Griswold as to the persuasive powers of Mr. MacDonald. As I remember it, Mr. Griswold in his paper, stated that Los Angeles was in a territory where the weather conditions there were very mild. In other words Mr. MacDonald has chosen as an example of successful joint pole construction a climate and natural conditions that most favor it. For the benefit of the TRANSACTIONS of the American Institute of Electrical Engineers, which are spread all over the world, and are certainly read all over the United States critically, I hope Mr. MacDonald in replying, will give some further information. I hope there will be considerable discussion bearing on the following facts.

In the first place, while there may be no hazards introduced by different types of lines on the same pole, beyond the capacity of the protecting devices, to take care of them, yet if the weather conditions were such as to make maintenance of lines themselves much more difficult than the increased frequency of the operation of those protecting devices and increased interruption to service and other things of that kind, might begin to come in in an economic way, while as now it does not. In other words, the cost of maintenance of lines and the cost of renewals of protecting devices and the cost, figuring them in cost of interruptions to service might begin to be in other districts where the wires are frequently down, a sufficient item of expense to warrant questioning whether or not joint pole construction or possibly underground construction where there are so many complicated circuits would not be the proper thing. Then the liability of the relations of the companies should be discussed if we have

opportunity. How do the companies share in liability questions as if a lineman that might be operating on one set of w res and injured on another or vice versa? What is the actual interference on the circuits and the incident hazard, and also what is the history of damage of joint pole construction with regard to the injury of employees?

Mr. Coldwell: in Portland we have only to a limited extent tried out this joint pole arrangement. With the telephone companies we have a few arrangements on individual streets and individual lines. In each case we have drawn up with them an agreement covering the matter of liability as well as of construction which should be adopted. It seems to me that the question of liability is one which is of very great importance, and I was rather surprised to hear Mr. MacDonald say there was really nine companies working harmoniously together in Los Angeles. It seems to me the content of his paper is a tribute to the broad mindedness of the engineers in Los Angeles and their " get together " abilities, not that I have not hopes that equal results might be obtained elsewhere, and that the same thing may be accomplished, but the actual carrying out and putting into practice of such an arrangement is really meritorious. I ask Mr. MacDonald if, in the practical working out of this scheme, each company maintains its own linemen, has access to the poles as it desires for its own wires, going and coming as they please, whether, if that is the case, two or three line gangs arrive at the same pole at the same time, with minor difficulties as a result, or does this Joint Pole Commission have its own crew of linemen for the companies altogether. It seems to me the latter would be the only way it could be satisfactorily worked out, and yet, if they are doing it in various crews in Los Angeles, I must be mistaken. I would like to hear from him on that point.

S. J. Lisberger: Does joint pole operation invite a greater hazard than individual pole lines? This is a difficult question to answer. Possibly if all pole lines were built on the same street the hazard would be no greater, maybe less, with joint poles, due to better pole clearances. But more hazard is introduced because it invites a larger number of wires to be located on the same lead. This is particularly true in territories where competition exists.

The speaker recalls an accident of recent date on a system where a wire of an 11,000-volt lead on the topmost crossarm broke. There was possibly 50,000 h.p. behind the short circuit. It was surprising to see what damage could be done. To those who have never experienced an accident like this it might be interesting to note that the short-circuit occurring in this case wiped out the entire pole line for two spans, there being 24 wires on the lead.

Joint pole line construction is advisable where not too many wires are concentrated on a single lead, but where such condi-

tions are likely to occur the speaker deems the problem worthy of careful consideration.

Does the municipality of Los Angeles pay its *pro rata* in the joint pole line construction?

H. R. Wakeman: I would like to ask Mr. MacDonald if the line extensions carried out by the various companies are not somewhat delayed owing to the amount of "red tape" it is necessary to go through in handling them through the joint pole commission. I understand that each time a company wishes to make any line extension it is at first necessary for the company to refer the matter to the joint pole commission which thereupon takes the matter up with the other companies before actual construction work commences. This naturally causes some delay and it seems to me it might be one serious disadvantage in working under a joint pole commission.

J. B. Fisken: In regard to the question of liability, it seems to me that the liability to accident is very materially decreased. In our town we have two telephone companies operating, and in some cases one telephone company has come along and strung their wires and cables right through the middle of our lead. We have had arc circuits grounded on their cables and various troubles. Now the liability to accident does not lie at the point of contact of those wires. Possibly a mile away a telephone lineman may be working on a line which he thinks is dead, but which may at another point be crossed with a high-voltage wire, then he gets hurt. Nothing has been said in regard to the question of cutting trees. I don't know how serious that is in Los Angeles. It is quite a serious proposition with us. We have had a great deal of trouble with the cutting of trees, and this spring we started a crusade on the proposition of tree cutting and I may state we had no assistance from the city government or the park commission. We decided to go to the property owners and ask for permission to trim the trees. So far we have had about three hundred permits this spring covering about fifteen hundred trees.

We have only had one complaint. One party gave us permission to trim the trees in front of his property. He had two lots, his house being built on one of them and the trees in front of his house were interfering, the others were not. We trimmed the ones in front of the house and then he came in and complained because we didn't trim the others. We have worked along these lines and have had no trouble about trimming trees. I would like to know if Mr. MacDonald's commission has any regular system of getting permission to trim the trees, and if they are assisted by the city government or the park commission or whoever has authority.

We have endeavored in the last few years, as much as possible to keep off the streets, but unfortunately in Spokane a great many of the finer additions are laid off without any alleys, so we can't go in the alleys. I remember one place where we tried

hard to get easements across private property to enable us to build the line there instead of along the street where there was one of our 60,000-volt lines. We could not get it because one property owner held us up. Now does this commission or does any one company have the right of eminent domain? Can they condemn in such cases?

Another thing I would ask is whether easements are taken in the shape of letters, or are they regularly recorded and as such show up in the Abstract of title to the property, in other words, are they permanent easements?

On the question of construction I don't know whether the state of California has a public service commission or not. If it has, does the public service commission allow the expenditure for joint pole construction to be capitalized in cases where lines which are removed are in good order? There is another question which comes very much home to some of us. In the state of Washington there has been a proposition submitted to the public service commission compelling the installation of guard wires above wires which have a limit of 5000 volts maximum where wires of a voltage of over 5000 volts are above them. Of course that applies not only in the towns, but all over the state. It means that if that should pass there would be probably five or six hundred miles of guard wires to be put up and in the cities of course that would be objectionable from the esthetic standpoint, as well as the standpoint of the consequent large expense for maintenance. Is there any such requirement in Los Angeles?

I noted with interest the system of numbering the poles which Mr. MacDonald passed over in a hurry. I think he might have dwelt a little longer on that. It happens to be a system we adopted several years ago, after laboring in vain with other systems. The only question I want to ask about that is, where there are poles in an alley, or across private property, is there any definite system in numbering? By that I mean, does the number of any such pole apply to the property east of it, or west of it, or south of it, or north of it?

Nothing was said with reference to the method of hanging large transformers. I don't know what the rules are in Los Angeles, but in putting up transformers we make a dividing line at about five kilowatts, placing small transformers on the regular crossarms and large transformers low down on the pole. In putting up say a 30 kw. transformer on a pole, does that have to be put in the space allotted to the company hanging that transformer or is there provision made to hang it below?

I hope Mr. MacDonald will answer Mr. Griswold's inquiry in regard to handling the gangs working because at home I can easily picture the situation where one non-union crew would be at work on a pole and a union crew would come along, to go to work on it.

J. E. MacDonald: I will try and cover briefly some of the questions that have been asked. Several have mentioned the

electric hazard or liability. We deal with that matter entirely as though we were on separate poles. We have had accidents in which we have been able to reach a satisfactory agreement. We immediately go out on the ground, or one or two engineers who are responsible go out on the ground, and determine the responsibility immediately. We don't wait until a law suit comes up, six, or twelve or eighteen months later on, and then try to fight it.

With reference to the distribution of shares on pole lines, the space for one, two or three crossarms for regular use, constitutes one share. The space for two crossarms with high circuits, that is, over 10,000 volts constitutes one share. The position for telephones would be included in the space and the position for a transformer would be included with one share. The position on a pole for trolley stand or bracket and for feeder or telephone is included in one share, that is, if a railway company has a transmission line on the pole and a feeder and stand they would be compelled to buy two shares in the poles. We have found that worked out very satisfactory.

Years ago, before we tried this scheme, we tried leasing and life rental, but it cost us more to keep track of such attachments than the thing was worth, and personally were I to take up the joint proposition in that way, I would say to a party go ahead and use the pole free of charge until such time as I tell you to get off. It would cost too much to keep track of the attachments on an annual rental charge.

Mr. Dunn has touched on the mild climatic conditions we have in Los Angeles. We are very fortunate in that respect. We have an ideal climate, although the rivers have to be sprinkled. In connection with Mr. Dunn's remarks, I want to give full credit for the specification which we adopted. The specifications are those of the American Telephone and Telegraph Co. of New York, and the public service corporations. I believe the American Institute of Electrical Engineers is responsible for those specifications, and I don't believe you will have any trouble in getting them. They are prepared by computations and I think that is about all that can be said with reference to it. They are complete in every respect. I believe that under the most severe climatic conditions they are suitable for combination use.

With reference to maintenance of poles. We have never experienced any difficulty in friction between our crews. In former years we used to experience a great deal of trouble, but we have crews of our happy family down there working on poles at the same time without any annoyance whatever.

With reference to maintenance work, I am happy to state I can leave this in the hands of the participating company entirely. When we are going to put in this pole, one company is given the first eight feet on top, and the next, the next eight feet, and the next, the next eight, and the telephone company the next eight

feet, and that is their property, no one else can intrude on that space, and one company is assigned the work of setting these poles and we have no trouble. Each company maintains its own wire, at its own expense. We don't permit the construction of joint lines where there are wires in excess of 6600 volts. We have some 6600-volt combination lines where the telephone companies are on the same poles, but very few of those. The standard maximum for lighting companies is 2400 volts. Ten or twelve thousand volts are maintained as far as possible, on each individual pole line.

With reference to the municipality, we do not participate in a joint arrangement, as Mr. Lisberger mentions. We cannot get permits for trimming the trees. We have a common blank which all the companies use. It is necessary for us to go around and get the consent of the property owners first; if it is a vacant lot, it does not make any difference. You have to get the consent of the property owner. Then you take that permit after it has been signed by the property owner to the Board of Public Works, the committee of the council, and they send an inspector out, and if it is all right, you get permission to trim the trees. We have had a great deal of trouble in that respect, but less trouble since we have been co-operating than we had before for the reason that one company would come along this week and get permission to trim the trees for high wires, and the next company would come along the next week and butcher the trees again; and the third week the railroad company would come along and cut a hole out to put a feeder in, but we finally devised an application blank which would work out very satisfactory if the city officers would take the authority which they possess and grant the permit without being afraid of being thrown out of office.

With reference to competition, I hardly agree with Mr. Lisberger and more so, since I have had this combination work, although dealing with some many companies, I am of the opinion that a regulated monopoly is the proper thing in this country.

With reference to Mr. Cramer's suggestions, in regard to extensions, I will say in some cases there are slight delays, but they are never serious. Recently there was a 48-acre tract being sub-divided to be covered with the poles. Now the streets have not been graded yet but we have made the arrangements already, far in advance, for the combination lines; but there are occasional instances where service is demanded, to-morrow, next day, or perhaps to-day, and in order to make connections, it is necessary to get two or more combinations. It may take 24 or 48 hours to secure the permit, but we are never delayed seriously.

I sympathize with Mr. Fisken with reference to his company setting poles in the middle of the street. That is one of the things we had to contend with in Los Angeles years ago. I have seen companies set everything from a 30-ft. pole to a 60-ft. pole to

secure everything from the earth to the sky to prevent a competitor from getting in, but that has passed.

The easements are permanent if you can get them and we usually get them. In a great many cases like the 48-acre tract I mentioned, the tract owner before he puts the sub-division on the market comes to us and says "we want poles in this subdivision, what do you want us to insert in these deeds and contracts." We have a fixed clause that runs something like this "Subject to a permanent easement for the installation and maintenance of overhead poles, wires, and conduits and so on," and they insert that right into the deed. In the other cases in the older districts where it is necessary for us to get easements on private property it is a little more difficult problem. Sometimes it is necessary to send a man around four or five times before you can get permission to cross the property, but these are rare exceptions.

We have had a Public Service Commission in California since March 23. I find under the law they have the power to enforce joint pole construction if they so desire. They also have the power to prevent paralleling and to protect competing companies. However, I have inquired a number of times as to the possibility of capitalizing that combination investment, and in making joint construction we find the opinion is it may not be capitalized, should be charged to maintenance and operating, but in our case it is not particularly serious. After being in service eight or ten years, the actual loss to the company in reconstructing joint poles will be very small. In the majority of cases the wires on those poles are proving inadequate, and when it is necessary to string a new wire there is a small remaining interest in the pole line that has to be charged to operating expenses.

With reference to guard wires, there was a law passed in California last year, and we have had a great deal of trouble in eliminating the clause pertaining to guard wires. Guard wires are a menace instead of a protection. That is the opinion of all the companies that have tried it in Southern California.

In reference to the numbering of poles on private property lines, it is the usual practice to take the east and south sides and on alleys to take the number corresponding to the side on which the poles are located.

With reference to hanging large transformers, one share includes space for a transformer, but when we have 10-kw. 15-kw. or 25-kw. transformers, it is usually the practice to encourage, as far as possible, a separate pole for such transformers. We do not permit a transformer to be on the same pole with a telephone junction box; and do not permit a telephone junction box to be on the same pole with an arc circuit or other lamp.

DISCUSSION ON "ALTERNATING-CURRENT SYSTEMS OF UNDERGROUND DISTRIBUTION" (LISBERGER AND WILSON), AND "AN UNDERGROUND SYSTEM AND A FEW DEVELOPMENTS" (CLARK), PORTLAND, ORE., APRIL 18, 1912 (SEE PROCEEDINGS FOR APRIL, 1912.)

(Subject to final revision for the Transactions.)

H. R. Wakeman: Messrs. Lisberger and Wilson have given us a very interesting and instructive paper on alternating current underground distribution. In connection with this paper I will ask Mr. Lisberger one or two questions. I understand that some of the alternating current feeders in the system described in the paper are not only underground feeders but also feed certain overhead districts adjacent to the underground district, and I would like to inquire whether or not this has presented any particular problems. Has it been found necessary to provide any protective apparatus either in the stations or at the junctions of the underground cables with the overhead system to take care of any heavy surges, such as are caused by severe short circuits?

I note that single-phase transformers are used in connection with the three-phase secondaries. On some streets at least, I should imagine that it might be difficult to find space to build manholes sufficiently large to accommodate three transformers and such other apparatus as is necessary. For this reason why is it that three-phase transformers have not been found more desirable than single-phase transformers, particularly as the cost of a three-phase transformer is somewhat less than three single-phase transformers and can be more easily installed.

S. B. Clark: I ask Mr. Lisberger what method he pursues in determining the size of mains and services to buildings. About the only available information I am able to get here is the connected load given by the contractor; if we cannot get it from the contractor we generally go to the underwriters. We have always had more or less trouble in determining what per cent of the connected load is the most accurate for certain classes of buildings I would like to know what method he pursues in working out this percentage.

I understand that he is using a certain amount of paper-covered cable. I should like to know how these paper-covered cables are terminated in the junction boxes—whether terminated only in lugs or otherwise. Does he ever have any trouble through moisture being absorbed by paper insulation in the boxes, and also if he ever experiences any trouble from moisture coming inside of the boxes through the difference in temperatures.

I should also like to know what kind of fibre he is using which he finds more suitable than slate or marble, and if he ever experiences any trouble with the fibre insulation on account of absorbing moisture.

J. B. Fisken: If Mr. Lisberger had confined himself to the alternating-current system of underground distribution, I would not have anything to say but I object to his apology for the

direct-current system. He states that there is a growing demand for alternating service particularly for low voltage sign lighting, and other devices that can be used only on alternating current.

I want Mr. Lisberger to come up to Spokane and I will show him any number of signs lighted with the direct-current low-voltage lamps and they give very good satisfaction. I note also he admits that direct current is required for elevators, and other type of apparatus because he states that is supplied at 550 volts. It seems to me instead of having the alternating current systems for some purposes and the 500 volt direct current system for others, with two services going to each building that it would be much more simple to put in one system that would do equally well, namely the direct current system. The advantages of that have been already pointed out to a certain extent. If an alternating-current feeder breaks down, it will take an appreciable time to transfer the load around some other way. If the direct current feeder breaks down, it will take the fraction of a minute probably to burn it off, if there is a battery back of it. It makes a fluctuation in the lights, and then everything goes on as before. I will admit that in a direct current district a block of city buildings may be deprived of service on account of the breakdown of the main, but that also applies to the alternating system. Mr. Lisberger is very fortunate in not having trouble on the grounding of this neutral wire at other points than at the station. A number of years ago we started putting in a bare neutral for the three-wire system, and we found that on account of the current that would get back over it, we had to take them all out and put in covered cables. The amount of current getting back seriously interfered with the regulation. Neither of the papers have touched on the question of tests, I mean as to periodical tests. I would like to hear what other engineers consider necessary with regard to that matter. For ourselves, we make voltage tests every two weeks, in every manhole between our cable sheaths, water pipes and rails. We also test the insulation once a month by means of applying 1200 volts a-c. In Mr. Clark's paper he states that the standard main is 1,000,000-cir. mil concentric. The safe carrying capacity as I remember it, of the concentric cable, is about 650 amperes whereas, two single cables will carry something over 800. It will appear that for short feeders where more current is required, that it would be better to use two single conductor cables than concentric cables. It would also be interesting to know whether 250,000-cir. mil main is sufficiently large to prevent serious fluctuations in the lines, due to large motors.

S. C. Lindsay: I would like to ask a couple of questions in regard to loading the feeders. What I want to know is this: Has the San Francisco Company and the Portland company a standard method of fixing the loads for the feeders? Of course the carrying capacity of the various size feeders is given by the manufacturer, but when used on underground work they give a lot of exceptions which are a good deal like the exceptions

to the rules for spelling in the English language; there are so many of them that when you try to remember and apply the exceptions you get lost. I would like to know if either of these gentlemen have worked along these lines.

W. H. Allen: I think both of these papers are very valuable ones. It has been particularly difficult to get any information along the lines of what has been done with alternating current underground work. Most companies use whichever system was adopted for overhead distribution in their early days, and very few plants have the possibility of starting with an equal opportunity to adopt either system. Many of us, have felt we would like to avoid the great expense of a direct current system, if possible, for there appears to be no question but that the alternating system is the cheaper. With a storage battery, the direct current system gives us the most reliable service that can be obtained, and for that reason, most large cities in the east have adopted that system. It remains for a few western cities to take the initiative on the alternating-current system without a storage battery current. Without a storage battery, the alternating current system is more reliable than the direct for the reason that in case of any slight interruption to the supply of power, the rotating machinery requires considerable time to be put back into service.

The principal points in which the alternating-current system differs from the direct-current system are in taking care of the transformers and in controlling and fusing the higher voltage circuits. The Pacific Gas & Electric Company seems to have worked out the latter point very well; it has developed junction boxes and fuse boxes which are admirable. Regarding the transformer vaults, after considerable investigation we have come to the conclusion that if an alternating system were adopted in the congested districts of the larger cities artificial ventilation would be necessary for the larger vaults. Some companies are operating vaults with transformers of capacities of 100 to 200 kilowatts without ventilation but I believe the temperatures obtained in some cases, are extremely high. I would like to hear from the representatives of the Los Angeles companies who have worked out this proposition very well.

With regard to the use of concentric cables I believe that in most where the cable capacity is limited by the carrying capacity of the cables, it will be found cheaper to use single conductor cables, and to install the extra duct necessary rather than use a concentric cable.

Mr. Waldmann: The statements in Mr. Lisberger's paper that they found it necessary to cut out the voltage regulators during the switching operation is very interesting in view of the fact in some of the high power installations that is adopted, and it is recommended for the purpose of cutting down the short circuit current. I presume that these voltage regulators are cut out only during the switching operations. I ask if he ever had any experience with the short circuits which have occurred

with the voltage regulators cut out, as regards the violence or the disturbance as compared with the disturbance when the regulators are in service. It would appear as though the effect of the reactance in the voltage regulators would tend to materially reduce the short circuit current.

W. M. Hoen: Referring first to Mr. Clark's feeder cables where they are tied into the mains; I would like to know what relation these fuses bear to the normal capacity of the cable? I also notice in the sample specification, given, for the low voltage splice that the materials are paper and varnished cambric to the exclusion of a great many others, which were tested. I ask Mr. Clark what materials they use in the splicing of the 11,000-volt cable, and I ask Mr. Lisberger, also, the same question in reference to his 4,000-volt cable, what materials they used in making the splices.

J. W. Welsh: I would just like to supplement my former question by asking if they have made any calculations as to whether there is any resistance present in the circuits due to the induction regulator, due to its reactance in connection with the capacity of the cable circuits.

F. D. Wilbur: I would like to ask both these gentlemen one question and that is in regard to the maintenance cost of these two systems. We have the two systems compared and I think it would be very interesting to know the cost of the maintenance.

A Member: I would like to ask too about the relative sizes of the manholes and distributing and cost of the two systems.

F. D. Weber: As regards the length of blocks in the two cities the blocks in San Francisco are exceedingly long and the blocks in Portland exceedingly short. Is there any reason why one system should be used in preference to the other?

S. J. Lisberger: Before closing the discussion on my paper I would like to ask Mr. Clark whether the cost of concentric cables is less than the cost of two simplex cables, bearing in mind the relative carrying capacities of the two types? Does not the splice in the concentric cable cost a great deal more than the splice on two simplex cables? Are not troubles experienced with pressure wires in the concentric cables; and what measures are taken to provide new pressure wires when trouble is experienced?

In the last four years all splices on our 200-volt simplex cables have been made with only varnished cambric and paper types; no filling compound has been used. We have not experienced a failure from this type of joint in four years.

Summing up the discussion of my paper; we have had no trouble on the mixed overhead and underground systems. That is perhaps due to the fact that we do not experience lightning in the part of Calfornia in which we operate; and, further, in most of our plants we operate a Y system with a grounded neutral, which, to a certain extent relieves the system of surges otherwise experienced on a delta-connected system.

In regard to Mr. Welsh's question; we have experienced surges only when tying feeders together, as described in the

writer's paper. The United Electric Light & Power Company, in New York City, have experienced severe surging on its system, which surging resulted in breaking down the insulation in the automatic regulators. The troubles and the remedies therefore are described in a paper by Messrs. Creighton and Sprong, in the Institute PROCEEDINGS about two years ago.

We use single-phase transformers for the following reasons:

1. Inability to get a three-phase transformer of any size through a 36 in. manhole cover.

2. From a standpoint of service, if you experience a burnout in a three-phase unit you have to remove the entire unit for repairs, necessitating a longer shutdown than if you used three single-phase units whereby you could keep service going on two of the phases continuously. With single-phase transformers the repairs would be much quicker and cheaper. The slight diffəernce in cost and efficiency is not justified, considering service conditions.

The size of the service from the manhole to the building depends entirely on the type of building supplied. From past experience we know the demands for a certain type of building, and proportion the service accordingly.

We have experienced no trouble with junction boxes sweating. The ends of the paper cables in the junction boxes are taped with varnished cambric and painted with a high grade type of insulating compound. We have had trouble with the transformers sweating. In certain cases iron rust has formed in the same shape as an icicle. We are endeavoring to overcome this by painting all parts above the oil with a heavy insulating compound and putting a fiber cover over the terminal board.

The insulating fiber referred to is "ebonite." We tested this material before adopting same for our junction boxes, and found that the breakdown voltage on the spacing that we use between terminals was 30,000 volts, where our working potential was 2,300. Fearing that this material might disintegrate in oil, we built an experimental box and kept it in service for very nearly a year. It showed no signs of disintegration, and the breakdown voltage was 37,000 volts, as against 30,000 volts.

We have experienced cases where the neutral of the direct current system has carried large railway return currents. We have had no like cases on the neutral of our Y-connected a-c. feeder system.

With reference to ventilation; the even temperature in the part of the state in which we operate has undoubtedly been in our favor, to such an extent that we have not found ventilation necessary. I understand, however, that some facts will soon be published in the *Proceedings* of the National Electric Light Association which will give authentic data on this subject.

To answer questions asked relative to material used in splicing; we have abandoned pure rubber entirely. All joints are now made with a layer of varnished tape over the bare joint, the other wrappings being oiled paper tape. On the 4,000 and 11,000-volt cables we use in addition a saturated type of paper

sleeve and collar, the joint being filled with a high grade insulating compound. No breakdowns have been experienced in three years with this type of joint. As stated before, we use no filling compound on joints where the potential is less than 750 volts.

Where using a three phase system, 9-ft by 9-ft. manholes are built, which gives ample room for three-50-kw. transformers and all junction boxes and cables which could possibly enter a system of this size.

Mr. Clarke: We have three different classes of cables to test of which I spoke in my paper. Our d-c. feeders are tested periodically. The frequency of test on these feeders is determined entirely by their showing when tested. The d-c. feeders are tested by a megger and I may add that the test system is taken care of by cards, as well as are the other records pertaining to the underground system. In one or two cases our feeders tested very low due to moisture. In two cases the manholes were flooded during the splicing of these cables—the paper insulation getting well soaked. It was dried by being boiled as well as possible. Knowing the condition of these two feeders we expect very low tests, and in testing two particular cases we use the Wheatstone bridge. Feeders showing low tests are tested every two or three weeks. If the feeder shows a very good test this card is placed at a future date and when that date comes, it is tested again by the test crew. We are not able to test the 11,000 volt lines quite so regularly as the others under the conditions we have for testing these lines. We are unable to get them for any length of time and another reason is that we are not prepared, where our underground ties to the overhead, to handle them at low test, the cost being prohibitive. As long as the 11,000-volt feeders show good on tests we do not test them often. We are able to test our 11,000-volt lines between substations very easily. All 11,000-volt cables are tested with a galvanometer for insulation resistance; we also make occasional capacity tests on them.

The 500-volt feeders are not easily tested on account of their being more or less tied together—it being a very hard matter to get at them for even a short and simple test, but we hope soon, as the 500-volt system is now a part of the railway system, to have a commercial system entirely separate, and as soon as this is done we will be able to test our insulation on our 600-volt cables without getting a shut-down on them.

There have been several remarks made in regard to the concentric cable—whether it is preferable to use a concentric cable or two single conductors. I think that it is a question that has been thoroughly thrashed out before, and I do not know whether it has been thoroughly determined if the one has an advantage over the other. In taking this up I will also answer one or two questions with regard to the load on feeders.

As stated before, our concentric cables are paper insulated. When buying cable we endeavor to get out paper concentric cables thoroughly saturated with insulating compounds. In all

cases we have not been able to put the proper terminals on the ends of our concentric cable in order to hold the coils when the cable heats. If we had been able to install proper terminals, I should say I could not see any advantage in installing single-conductor cables. The concentric cable, of course, reduces duct space to a great extent and the cost of the two single-conductor cables is higher than one concentric cable. The maximum load we allow for 1,000,000 concentric type feeders is 1,000 amperes. We do not consider it safe to work cables with any greater load. The rated safe capacity of a concentric cable is 600 and 700 amperes. With approximately 1,000 ampere working load the cables get quite warm. In case cables are paper-insulated and thoroughly saturated, having proper terminals, giving the oil no chance for escape, I do not consider that the load on the cable is prohibitive from a safety standpoint but do not consider it economical. When you begin to work a type of cable similar to the concentric cable and of the kind and class we are using above 850 amperes, your economy decreases and your losses increase.

Mr. Lindsay, asked if we have noticed any fluctuations from power loads on our system caused by the use of our 250,000 cir. mil. mains. In cases where we have 250,000 cir. mil. mains and the loads are not extremely large, as far as we have been able to determine there is very little fluctuation due to this size of main. Wherever there is a heavy load that the mains will not properly take care of (these cases being very few) we have installed large mains or have installed at that point the necessary feeder. We do not make it a practice of installing larger mains than 250,000 cir. mil. The general practise is instead of installing large mains to add additional feeder capacity.

One speaker brought up the point of the handling of the d-c. system versus the a-c. system under operating conditions; making the statement that the a-c. system was more easily handled—referring to interruptions in feeding lines—than the d-c. under these conditions. A short time ago we had a severe test in that respect and I think our operating conditions here were as bad as could possibly be hoped for by anyone. This came up during our last silver thaw. It is true it took some little time to get the a-c. motor generator set stopped and started but with a little hard work it was done successfully, there being no interruption of service on the d-c. system on that account. During that time I expect that the machines were handled three or four times during the course of a few hours, changing from one feeder to another, these feeders being affected mostly by overhead lines which feed our feeding lines coming into the center of the city, causing the load to be transferred to different feeders. In transferring these feeders, of course the machines had to be stopped.

Another question was asked in regard to relative fuse capacity that was considered safe for use; also regarding the number and size of cables in our junction boxes. Our feeders (I am speaking primarily of the 120/240 volt concentric feeders) are tied in solid to the bus at the station. The feeder junction boxes are

fused with the feeder stubs in nearly every case with 1200-ampere fuses which is allowing a small percentage to go on in case our feeders are overloaded for a few moments.

There is another thing that might be considered in the matter of fusing for overloads and that is the difference between the rated capacity of standard fuses and the actual blowing point. In making tests of standard fuses, we find that the fuses rated at 1,000 to 1,200 amperes will not blow until a load of perhaps 1,500 amperes is reached. In case of a 350 ampere fuse, if I remember rightly, it did not blow until a load of from 450 to 500 amperes was reached which gives a very low rating for the standard rated load. In fusing the main stubs coming into our feeder junction boxes, we use in nearly every case, 350-ampere fuses. In two or three cases we have been obliged to use temporarily 500-ampere fuses on these 250,000-cir.mil. mains. The mains, of course, being paper, withstood the load very well.

Another question was asked regarding the insulation on splices for the 11,000-volt cables. I have to a certain extent done away with all rubber insulating material. Considering the heating effects of overload on rubber, I consider varnished cambric tape far superior. So far, our 11,000-volt cables are not overloaded and I do not think that there will ever be any danger from this source. We are at present using two layers of gum-faced tape—one half lap—following the rest up with varnished cambric. These splices are filled with No. 150 Ozite compound. In cases where we have 11,000-volt splices made up in places where the temperature is extremely high, we use the No. 75. It is a little harder compound and stands the heat better. During our first construction, in several cases where we installed 600-volt feeders, we used the G. E. 67 or 227 compound. Later these 600-volt feeders were overloaded and heated. The 67 or 227 compound in the terminals on these cables seemed to dissipate into the cables, and at the present time wherever we have a cable that is liable to be worked under such heavy overload conditions we use the harder compound.

Someone asked for the comparative sizes of manholes. Our manholes in the underground district with the exception of some of the larger manholes where we have as many as 50 or 60 ducts going through them, average about 6 ft. by 6 ft. Some are made egg-shape, some oblong, others are made square. Mr. Lisberger I think answered the question regarding the length of the blocks. I do not think the length of blocks would in any way affect the distribution of a-c. or d-c. underground. Mr. Lisberger also brought up the question of load pressure. I am of the same opinion that he is although I did not express it; that is, where pressure wires are placed with the strands of a concentric cable they are not reliable. I favor a separate pilot wire system. There are a great many advantages gained in doing this as you can use them for any number of purposes, while the pressure wires in the concentric cable are only available for one purpose.

DISCUSSION ON "ELECTRIC BRAKING OF INDUCTION MOTORS" (SPECHT), PITTSBURGH, PA., APRIL 25, 1912 (SEE PROCEEDINGS FOR MAY 1912.)

(Subject to final revision for the Transactions.)

H. E. White: I have been greatly impressed with one particular point to which I think attention should be called, that is, it is impossible to consider the induction motor, or the direct-current motor alone by itself. Mr. Specht's paper shows clearly what can be done in using an induction motor with electric braking, but it would appear that the admission must be made that after all it is not an electric braking, but a reverse power system which is described. I recall one application where this was tried. The hoist did not always attain full speed, at least not in the preliminary test, and after coming to rest, would reverse without coming to rest at the point where the automatic devices that had been provided should have stopped it.

Several times I tried to find out what could be done by applying direct current to the primaries of induction motors. I know of one successful case—it happened to be a very high voltage motor. However, if you take a motor of the voltage that is favored in steel mill work, 220 volts, it will be found that the direct current voltage, applied directly to the terminals which will give a good braking effect, will be found to be a very low voltage, only 3 or 4 volts in some cases.

It should be brought out prominently in this connection, that the direct-current motor possesses possibilities of control that the alternating-current motor does not possess, and with the advent of the series contactor this difference in favor of the direct-current motor seems to be very greatly increased. The designers of the motor generally will neglect to consider the problem of controlling it. The time has come when both must be considered together and nothing can be considered by itself.

H. F. Stratton: Mr. Specht, in his comparisons of the relative merits of dynamic braking wih direct-current and alternating-current excitation, says that with the direct-current excitation, only a weak braking torque can be developed near standstill, and and he would have us believe that, at the instant standstill is is reached, the braking torque becomes nil. This would be equivalent to saying that dynamic braking on direct-current motors becomes very small at the time the speed of rotation has reached practically zero, and certainly does not persist at all at standstill. While this statement appears plausible from an academic standpoint, it is, as a matter of fact, not true. The dynamic braking current does exist for an appreciable length of time after the motor has stopped, owing to the desire of the braking current to keep flowing in the same direction; in other words, this is an induction effect. We have had come to our attention motors driving cranes, which actually caused the wheels to skid upon the application of dynamic braking *after the motor has come to rest.* The motor was absolutely locked

stationary by the dynamic braking current while the crane skidded a distance of several inches.

Gano Dunn: I should like to give a little matter along the line of Mr. Stratton's talk, in respect to having worked with the principle he mentioned, only to a greater extent, a number of years ago. The real situation is one in which there is resonance between the magnetically stored energy, on the one hand, and the mechanically stored energy on the other. They are, as you might say, in a different phase, and when I was conducting these experiments it was not at all unusual to see when a proper relation had been arranged between the braking resistance, and the inductance in the braking circuit, the motor not only brought completely to rest, but start running backwards in many cases very rapidly. It is perfectly possible, in other words, for advantage of this phenomenon to be taken to further braking schemes of all kinds.

An interesting experiment may be made in connection with little hoist motors which brake by short circuiting through a certain fixed resistance. I have seen that resistance so adjusted that one would think a metal bar had been put through the spoke of the pulley and suddenly withdrawn, so violent was the stoppage, and so elastic was the spring back, that for a moment you did not know that the motor had been stopped at all, since you finally saw it come to rest, after running in the opposite direction.

I believe there is no equivalent for this in connection with the alternating-current braking that Mr. Specht has brought out, because, as has been pointed out, that is really reverse power braking but the current braking that I have been referring to is really, a balancing of stored magnetic energy on the one hand, against stored mechanical energy on the other hand, which takes place when there is a suitable adjustment between the amount of inductance and the amount of resistance. It is capable of very useful employment.

John C. Reed: The possibility of extracting the energy from a moving mass by means of dynamic braking has become quite common but I do not remember ever to have heard or read any discussion as to the possibility of stopping the mass and then extracting the energy. It is my belief, however, that this can be and is being done. I am familiar with an elevator used in connection with a blast furnace where I believe this is being done. The elevator referred to is not a skip hoist, but a straight vertical lift and anyone can readily appreciate the difference, since a skip need only be stopped within a limit of five or six inches, while in a straight lift the floor of the cage must come flush with the top floor since if it is one-fourth inch too low it is difficult to remove the heavy buggies from the cage, while if it is one-fourth inch too high it is difficult to put them back on again, more than one-fourth inch is not allowed.

If the weight of the load on the elevator never varied it might be possible to set the cut-off so that the drift would always

bring the floors level, but since the weights vary as much as a hundred per cent satisfactory operation cannot be accomplished in this way because the cage will run high or low depending upon whether the load is less or more than that for which the cut-off is set. This trouble was overcome by short circuiting the armature an instant following the cutting off of the current. This apparently stops the elevator instantly and all the brake has to do is to hold the load. I am not prepared to say whether the dissipation of the energy contained in the moving mass which must take place within the motor, occurs immediately preceding or immediately following the stoppage, but I am inclined to believe that some of it follows the stoppage.

Clark S. Lankton: I would like to mention one instance in alternating-current braking which is working satisfactorily. The motor is a 1200 h.p. induction motor working in conjunction with a heavy flywheel. The transformers feeding the motor are delta connected and two transformers have a central tap, whereby half voltage is obtained with an open delta connection. By means of a double-pole double-throw switch this half voltage can be applied in the reverse direction, thereby establishing an effective plug. Three to four minutes are ordinarily required to stop against the friction of the roll train but with the plug only thirty-five seconds are necessary.

H. C. Specht: Mr. Lankton told us, as I understand from him, that the alternating-current braking with the flywheel on the motor, takes from three to four minutes to stop. This is a rather long time for braking. It is generally possible to brake almost any induction motor with a flywheel connected to it, inside of 10 seconds if there is a proper resistance in the circuit and full voltage applied to the primary. However on motor generator sets, particularly of higher speeds, the time of stopping will be considerably higher.

C. S. Lankton: The flywheel was directly connected with the motor all the time. Ordinarily the motor would run, with the flywheel connected approximately from three to four minutes, but by putting on half voltage V-connected plug, the motor would stop in about 35 seconds.

Gano Dunn: I believe if this were a case of certain flywheels being brought down in ten seconds, the title of the paper ought to be what by a misprint it actually was when the first copies came from the printer, " Electric Breaking of Induction Motors."

C. S. Lankton: Even with the half voltage, we get about a load and a quarter in amperes on the motor. I think it would be very severe to stop it in 10 seconds.

DISCUSSION ON "NOTES ON THE USE OF ALTERNATING CURRENT IN UNLOADING COAL" (RYERSON AND CRANE), PITTSBURGH, PA., APRIL 27, 1912. (SEE PROCEEDINGS FOR MARCH, 1912).

(Subject to final revision for the Transactions.)

Wilfred Sykes: Having been more or less responsible for the first of the man trolley equipments installed at Duluth using alternating-current, I would like to draw attention to a few points in the paper. The maximum rate of operation of the man trolley bridge has been given as 500 tons of coal per hour. I have some tests showing that in the case of one test, extending over a period of five hours, in which twelve minutes delay was incurred, due to waiting for the boat, leaving a net period of 4 hr. 48 min., the bridge made 389 trips; about 40 per cent of these trips were to the first hopper for loading direct into the cars, and about sixty per cent of the trips went back 150 feet on the pile. That gave an average rate of operation of 74 trips per hour. The capacity of the bucket averaged a little more than five tons, so that the total amount of the coal handled was about 2050 tons. The maximum rate of operation over one hour was found to be 83 trips; the number was about evenly divided between trips to the hopper and trips to the pile.

In the paper it is stated that the dynamic braking of the alternating-current motors has proved satisfactory but is expensive. I would like to question that point. The use of dynamic braking was not contemplated at the start, was not really figured on, but the builders of the present bridge got into trouble through mechanical brakes and had to find some way of operating the equipment, the present equipment, which was finally arranged to be with alternating-current; but they did not know what they would run into, and they started in to put in a small motor-generator set for supplying direct-current to the hoist and the brake motors.

As a matter of observation I might say that the power consumption is very small, and you can easily see that, because the current through the stator is about one and one-half when braking the full load alternating-current of the motor. The voltage required is very low, because you only have to overcome the ohmic resistance of the stator windings. The motor-generator sets for one of these bridges has a capacityof 140 amperes, direct-current, at 40 volts, so you see it is quite a small affair, and the power consumption is somewhere in the neighborhood of thirty to forty watt-hr. in ten hours. As the current costs somewhat less on an average than one cent per kw-hr. the power cost is probably about fifty cents a day, twenty hours operation. On similar bridges, in which they have mechanical brakes, using band brakes, originally starting off with wooden plugs, but since that was unsatisfactory, afterwards using asbestos lining, the cost varies from about $4 a day, in the worst case, which is a pretty bad case, down to $2 a day. It is hard to obtain reliable

figures on the cost of maintenance of brakes of this kind, but those are the figures I have been given by the operators.

I want to draw attention to one feature of the man trolley bridge in the coal handling plant or ore handling plant, which should receive the closest attention of the designers, and that is that you must make the movements which the operator has to perform as few as possible, and the operator should be required to make only a very small expenditure of energy, because when a man is on a bridge for ten hours and is operating at high speed, he cannot put much energy into each operation, otherwise he is worn out and the quality of the attention which he can give his work is impaired. That was one of the reasons that led to the adoption of dynamic braking, because when a man is lowering a bucket and exercising the greatest care, where they have dynamic braking, he starts the bucket going down before the control is stopped, throws on one controller notch and lets the bucket go down 200 feet and about that time the bucket has passed through the hatch, and he cuts the controller off and puts the brake on. The introduction of the dynamic brake has facilitated operation and increased the capacity very materially.

Where you have a mechanical brake it is necessary for the operator to give more or less attention to that, whereas with the dynamic brake he does not think about the thing at all, but is chiefly concerned with centering the trolley over the hatchway. That is one of the points that makes a bridge with dynamic braking much easier to handle than a bridge with mechanical brakes.

On this first installation, and indeed on quite a number of installations, seven or eight of them, the controllers are operated by compressed air. It is necessary on these bridges to have compressed air for the clutches, anyhow; I think some have tried to use the electric clutches, but I do not believe they achieved any great success. The company which has built most of the bridges is very strongly of the opinion that it is necessary to have compressed air in order to obtain anything like reliable and quick operation, and the control as originally laid out in the majority of cases is with air operation. One of the reasons for using air operation is that this type of switch has been tried out in railway work, in which they are able to obtain great pressures at the point of contact; and any one who knows anything about brake control, knows that if you have given a pressure on the contact and a large force for opening the switch, you have increased the reliability very greatly, and that is one of the reasons that led to the use of air switches. Then, again, although alternating-current switches have been developed since that time, I believe it is a matter of opinion among operators which is the more reliable, and a great many operators prefer air-operated switches because of the fact you have in the switch 200-lb. pressure on the contact and a force of about 150 lb. to open the switch, so you are sure of very reliable operation. In one of these plants there was some

little trouble due to the moisture in the air freezing and blocking up the pipe, but with a proper arrangement of the air pipe so as to drain the moisture out of the system, I do not think there is any trouble now encountered in even the worst weather.

The paper has mentioned also the method of distribution, in one case using 13,000 volts, collecting the current at 13,000 volts, having a transformer on the bridge, and in another case having 440-volt distribution with stationary transformer. I think that is a good deal a matter of opinion. There is no question that with the 13,000 volts you can obtain a good deal better voltage regulation at the motors, and my experience has been that for work of this kind you want to get all the voltage you can at the motors, so that you can get as much torque as possible in the motors during acceleration, because if you do not do that the operators will complain.

There has been a little trouble due to the accumulation of soot on some of the insulators. I do not believe that amounts to much now because in the first installations they put in too small insulators and did not appreciate the fact that locomotives would run beneath the line.

With the low-tension distribution, unless you use a great deal of copper and subdivide the lines, the voltage regulation is very poor when the bridge is working at points furthest away from the transformers.

As to the most desirable arrangment of these bridges, I believe one point has been overlooked. It is stated that the most desirable arrangement of the man trolley bridge would be to have the peaks during the racking and hoisting the same. That would be all right, if the peaks did not occur simultaneously, but, the way the bridges are operated, the hoist is stopped, sometimes it is slowed down going through the hatch, and accelerated again, but as soon as the control motion is thrown off the contacts overlap, and that is the worst test for the man trolley bridge—so I do not think that statement would stand. The most that could be said, I think, would be that that would be the most desirable arrangement when the contacts did not overlap. If that arrangement had been used, on the existing bridges, the contacts would be very much higher than they are now.

In connection with the question of charging, I think I will enlighten Mr. Crane a little as to a conspiracy that was hatched up at one time, a method of beating the power company. If you put in a flywheel set and use the motor-generator set with a flywheel, and have an arrangement to introduce neutral resistance in the rotor of the motor for a brief interval, so that it will drop the load for two or three seconds, causing the graphic wattmeter to go back to zero, then you can all be charged on the one-minute peak. It is, however, possible that your input to the set will be practically the average load and, therefore, you can cut down your charge for reservation, and consequently your kw-hr. rate.

There is one difficulty, it seems to me, which is a pretty serious difficulty, and that is, having as the basis of charge in such a system the necessity of depending upon some form of graphic recording wattmeters. We all know that alternating-current meters have very rapid fluctuations of load, are likely either to lag too much or overshoot, and it is possible to have a good deal of trouble in that way, and to have an endless argument with the customer especially if he finds out that the motor is overshooting. If he does not find out, it is all right. That is a point which has arisen and causes a great deal of bad feeling. In this particular case, where you are dealing with large operators, they can generally understand the justice of the system of charging, with a different basis of charge for different conditions. Generally, where you have small consumers who do not study these questions, you have a good deal of difficulty in explaining to them just why you should have different bases of charging.

The question as to whether the bridges shall be equipped only with alternating current or only with direct current, is one of importance where you are handling man trolley bridges. That is the bridge which I believe is the coming bridge, and one which will be used more and more every year. It is comparatively new, but the breakage of coal is a good deal less with that arrangement; and you can get very large capacity, and with the conditions in Superior, or in the Northwest, the breakage of coal is a very important item, especially when the dock may handle over a million tons a year. A very small reduction in the value of the fuel shows up as quite a large item at the end of the year.

In one of the installations most recently contracted for—not yet in operation—the man who is building the dock contracted for direct-current, and that makes it necessary to have synchronous converters; in addition he has also planned for a fly-wheel equalizer, so as to have a direct-current motor on the bridge, the idea being that the direct-current motor is more reliable than the alternating-current motor and more accessible for repairs, and does not have to be repaired so often. That is a pretty serious matter. I do not believe that in the present state of alternating-current motor design these criticisms are justified, but the fact remains that such a dock is being installed and is to be put into operation this season, and if there are any present connected with the operating company I would like to hear their views on that question, because it is a matter of unusual importance and has been exploited a good deal by some of the power manufacturing people.

On the question of using equalizing machines, I quite agree with Mr. Crane. I do not believe it can be justified, on the rate of charging. If we take, for instance, the minute indicated peak loads, then we have a different condition, but I do not believe that with the present system of charging the use of the equalizing machine is justified.

C. T. Henderson: I would like to add a word or so to the remarks made by Mr. Sykes regarding the direct-current instal-

lation that is being made at the present time. It is a very pertinent fact that this direct-current installation is being put in for a company which now has a dock equipped with alternating-current motors. This would make it appear, at first glance, at least, that the dock people are not altogether satisfied with the alternating-current dock, and are looking for something better, either in the way of reduced cost of operation or convenience of operation, or perhaps both.

On the general subject of alternating current versus direct current for dock operation, it would appear to me that Mr. Sykes has not dwelt with sufficient emphasis on the fact that to get satisfactory operation out of alternating-current motors the voltage must be strictly maintained, because with alternating-current motors the torque that is available is in proportion to the square of voltage, and it does not take much drop of voltage to slow down the machine very appreciably, or, perhaps, on account of lack of starting torque, put it out of operation entirely. With the direct-current machines reduced voltage does not cause any material reduction in torque, but simply a reduction in maximum speed of operation; that is, ultimate speed of movement attained.

On the question of dynamic braking, it does not appear to me that the people in the Northwest, or in fact the coal handling people in general, have been fully alive to the advantages of dynamic braking. There was a time when dynamic brake control was absolutely unknown; there was a time when no one ever thought of retarding the descending bucket on coal or ore handling machinery in any manner except by means of a mechanical lowering brake. Dynamic brake control was first installed, I believe, in connection with ore handling machinery, and it solved the problem of proper retardation so beautifully that I do not believe today that any ore handling machinery is being sold that is equipped with mechanical lowering brakes.

In comparing direct-current dynamic brake control with alternating-current dynamic brake control, it should be borne in mind that while, in the present state of the art, it is possible to get a certain amount of dynamic braking action with the alternating-current motors, they cannot entirely duplicate the performance of direct-current machines. For example, on the Duluth and Superior installations the alternating-current motors have their stators excited with direct current and are used to retard the descending load, but no attempt is being made to have the alternating-current motor slow the load down to practically a standstill before the holding brake is applied, whereas on the direct-current machines—the ore handling machines particularly—such procedure is almost the invariable practise. As a result, I can say that in one installation, which I have followed very closely for the last four or five years, the hoist brakes have so very little to do that the brake bands have not been renewed, and this, I believe, is a considerably better performance than has

ever been obtained on alternating-current bridges even with the dynamic braking.

On the question of overlapping peaks, it has been pointed out that with the man trolley rigs the highest peak is obtained at the moment when the operator starts the trolley, while he is still hoisting. On the direct-current machines which are being installed in the Duluth-Superior region this spring, I believe that series parallel control is being used on the trolleys, and provision is being made for preventing the operator from throwing his motors into parallel until the hoist operation has been completed—this with the idea of reducing the maximum demand that can be made by the bridge, and at the same time permitting the operator to get his trolley under way before the hoisting operation has been completed.

Returning to the question of alternating current versus direct current, and particularly to the last paragraph of the paper presented by Messrs. Ryerson and Crane, it might be interesting to a great many here to know that in addition to this one company that is putting in a direct-current dock at the present time, and which has an alternating-current dock that has been in operation, I believe, for more than two years past, there are two other installations being made in that same district and both are direct-current installations. All of this, I believe, goes to emphasize the fact that the coal people in that territory are just beginning to realize the advantages of dynamic braking as obtained on direct-current machines, just beginning to realize the advantages accruing from the use of series-wound motors for bridge service, and just beginning to fall more in line with ore handling machinery practise.

Just one other point, in regard to current consumption. I was very much surprised to note in the comparative table of different types, given in the paper, that a minimum of 1.09 kw-hr. per ton and maximum of 1.76 kw-hr. per ton are indicated as being required for the handling of the coal in that territory. I had on several occasions been given figures that were considerably lower than those, but I cannot, of course, vouch for the accuracy of them. In Milwaukee, however, I have made a number of tests on coal docks, and in one installation, for example, that of the Milwaukee Coke and Gas Company, the average power required over a period of one month was 0.47 kw-hr. per ton, which figure includes the power required for the operation of the man trolley as well as the power required for the moving of the bridge.

It should be remembered in this connection that this particular bridge is of the type having a center pivot, and therefore does not require as much power to move it as the type of bridge which moves straight down the dock.

There is another installation in Milwaukee on which I made a series of tests, and in one case a cargo of coal—6000 tons—was unloaded with an average consumption of 0.25 kw-hr.

per ton. This figure does not include any energy for moving the bridges up and down the dock, because they were only moved a few feet at a time, only far enough to move them from one hatch in the boat to another. The largest handlers of coal in Milwaukee have given me a figure of 0.58 kw-hr. per ton as an average for their entire installation, which comprises some five or six docks, and in view of the figures I have submitted here it appears almost inconceivable that as much as 1.76 kw-hr. per ton should be required by the man trolley, type No. 1, as discussed in this paper.

E. Friedlaender: I would like to know if any fatal or minor accidents have occurred at these plants on account of using high-tension lines.

I would also like to ask how much of the load is actually lowered and if the empty bucket is heavy enough to overhaul hoisting machinery from a standstill and go down by its own weight. I understand coal handling docks are similar to ore docks, where the load is dropped by opening the bucket in its highest position. If this is the case, very little dynamic braking would be required, especially if the bucket is not too heavy.

Wilfred Sykes: There are one or two points raised by Mr. Henderson I would like to answer. In connection with dynamic braking on the alternating-current motor, the bucket is not stopped—the operators do not attempt to stop the bucket with the dynamic brake. They are very well satisfied if they can set the buckets running down, and forget them until they have gone to the hatch. The wear on the mechanical brakes when you do this is very small, and a set of linings will last several months with proper handling. You cannot get quite as good a record with this form of operation as you can with the direct-current operation, as mentioned by Mr. Henderson.

I did not mention that the brake is also used for the stopping of the trolley. The dynamic brake is not depended on entirely. As a matter of fact the brake is thrown on and the final stopping done with the mechanical braking, but the reduction of the wear on mechanical brakes by using direct-current on the stators is very great, and the life of the brake shoes has been increased ten times over what it was originally. We have also avoided a great many difficulties due to the iron dust, etc., getting into the windings.

Regarding the man trolley bridges I also notice the point raised by Mr. Henderson, as to the amount of kw-hr. required per ton—I do not believe that figure is intended to represent the power actually taken by the bridge. From the figures given, I think that must also include the power consumed by all the other motors required around such a coal dock. I have personally made many tests up there, and find, depending on what part of the dock you are delivering the coal, that the power required varies from about 0.4 to 0.6 kw-hr. per ton. That would show, however, a kw-hr. per ton for the actual input of the bridge. I

believe this figure is borne out by the records kept over a considerable period by the operators.

The power required in the moving of the bridge, referred to by Mr. Henderson, is not very great anyhow—it is a very small percentage of the total power required for the operation of the equipment.

The point raised by Mr. Friedlaender about how much of the load is lowered is one which I thought would be clear, and would show why the dynamic brake is used. These buckets weigh anywhere from 15,000 to 18,000 lb., and with this man trolley, type No. 1, you cannot very well arrange for a counterweight. The loaded bucket weighs from about 27,000 to 37,000 lb., so that approximately 60 per cent of the total load lifted consists of empty buckets which have to be lowered every trip.

As far as accidents due to shock are concerned, I do not believe there are any. The only accidents I know of up there are due to men being caught between the trolley and some portion of the structure, or to the wrecking of the plant when one of the trolleys fell off the bridge altogether, but there was nobody killed.

R. R. Selleck: I was connected with the company that put in the docks shown in Figs. 5, 6 and 7, and was located at Duluth for about four months in that connection, and I became quite familiar with the handling of coal on these docks.

Now, there is one thing I would like to say at the outset, and that is that it is my belief that the alternating-current is just a makeshift when it comes to handling coal or ore. It does not lend itself very rapidly to dynamic braking, and, as has been discussed here at some length, dynamic braking is absolutely necessary for quick operation; speed is what the men are after who own these docks. That is the first consideration. You will note by referring to the paper presented by Messrs. Ryerson and Crane that they give the weight of the trolley in one case as 50 tons and the weight of the trolley in another case as 40 tons. The 50-ton trolley is the one which had the dynamic brake. As a matter of fact, it came nearer being 60 tons, because I know the other one weighed 52 tons, and you will notice the appearance of the trolleys—there is certainly a difference of 10 tons in the weight of the two trolleys. That is of importance when it comes to the designing a bridge structure, so that if you can reduce the moving load 10 tons, you will materially reduce the material in the bridge structure, and that is the first consideration, of more importance than the question of who is going to build the bridge.

It does not seem to be an economical plan to put on a trolley any more material than is necessary. By using dynamic braking, which requires a small motor-generator set, and in addition, an air compressor set, considerable weight is added. A man trolley does not have much spare room, either in the cab or on the superstructure. At best it is not a very commodious place, and anything that tends to cut down the amount of apparatus re-

quired on the trolley is of considerable importance, especially to the man who is to build it. So I do not think that alternating current is going to prove the big success in the handling of coal that was at first predicted. As a matter of fact, as has been already stated, several firms up there are going to direct-current.

A few words in regard to distribution. It has been stated that one of the docks takes energy at 13,000 volts, and puts it at that pressure directly on the bridge. The energy is taken off the catenary trolley system, transmitted across the bridge to the transformers, where it is stepped down to the voltage required on the motors.

Some emphasis has been laid on the relative cost of these two systems, *i.e.* 13,000 volts vs. 440 volts. As a matter of fact, I was connected with the making up of an estimate for the equipment that was to go in one of the docks at Duluth. This job was figured for 220 and 550 volts direct-current, also for 440 and 13,200 volts alternating-current, the idea being to arrive at these costs very carefully, and we found that 550-volt direct-current transmission was the cheapest. Then we got to 220 volts direct-current, then 440 volts alternating-current, and lastly 13,200 volts alternating-current, which is considerably higher than any of the others. That is due to the fact that you must put up a special trolley construction. That installation in this case was in the form of a catenary, and you must use quite an expensive insulation system, and in carrying the line across the bridge considerable care must be exercised to avoid grounds, so it figures out at the highest price of all, while your copper, in the case of the 440-volt system, where there were two parallel lines of 750,000-cir. mil. cable, six of them, each running 1200 feet, runs into money. Notwithstanding that, we figured it was a cheaper installation than the 13,200 volts.

Mr. Sykes made mention of the fact that it was necessary to have air on one of these bridges to operate the clutch. He said that electrically operated clutches had been used, but did not give very good satisfaction. On this 440-volt bridge the clutches are operated by electricity, 48-in. clutch electrically operated, and to my knowledge the clutch has not given any trouble. It is working very satisfactorily; but, of course, you cannot throw a clutch in like one that is manually operated; you must have some auxiliary system to throw the clutch in—but as far as the operating of the clutch by air is concerned, it is not necessary to have that. It is not necessary to have an air equipment on the alternating current bridge, that is the point; because it seems to me to be foolish to load up a man trolley with a whole power plant.

Now, one word in regard to regulation. It has been pointed out that the regulation on the 13,200-volt system was better than on the 440-volt system. I beg to differ on this point. We had three bridges on this deck in operation at one time, and we had them at that time as far as we could get them away from the transformer house, about 1,000 feet, and we were trying the regu-

lation—that is what we did it for. We could not get any very satisfactory voltage readings, due to the "kick" of the voltmeter, and, of course to the fluctuations that are instantaneous, but about the best we could do was to calculate that we got a drop of about 10 volts. If with three bridges in operation we got a drop of 10 volts, you would not notice any fluctuation in the pilot lamps on the trolley, so our voltage regulation was very good, and we did not have any trouble at all.

That answers the question raised in regard to the torque of alternating-current motors on a coal or ore bridge. If your distributing system is properly designed you will not get into any trouble with the torque falling off. We do know that it falls off as the square of the voltage, but if the distributing system is properly designed and sufficient cross-section of copper put in to take care of it, you will not get any appreciable drop of voltage and so there will be no difficulty there.

There was another question in regard to the lowering of the load. Of course, the breaking of the load of the coal is an important item to the owner of the dock. When we first started to put coal on the dock they insisted on our lowering every load—that was when we were dropping about 30 feet from the ground up to the bucket—but after we had a thin layer of coal on the dock they did not insist on our lowering the bucket, and after that the operator would run out the bucket and allow the coal to fall down. While some breakage might result, it was not considered serious. My experience has been that only the lowering of the bucket over the first layer, is required, probably the first ten feet of coal on the dock.

Regarding the operation of these machines and the dynamic braking, as has been said, complications follow when you put dynamic braking on an alternating-current system; and anything that makes more complications necessarily decreases reliability. The intelligence of the men who are on these bridges is not of a very high order, and what the operators want, what the owners of the dock want, is speed—they want to get the boats dispatched as quickly as possible, and the men that are in them are a rough and ready sort of fellows (they do not seem to care whether they are killed or not) and their first and only thought is to rush the unloading of the cargo. All they are thinking of is to get the coal out of the boat, and they want something that is going to help them do this quickly; and for that reason I think that the dynamic brake, because it increases complications and decreases reliability, is something that is not very desirable for that class of work.

One speaker raised the question of safety appliances in these machines. We do not have very many safety appliances of any kind. As a matter of fact, I was in a trolley when it went off one of these bridges, and went down 65 feet. No serious harm was done.

R. H. Hellmund: One of the speakers said that it was not possible to reduce the speed to zero by dynamic braking. That

statement is not correct. You can go down to three per cent of the speed any time if the requirements are such that you want to do it. The lowest speed you get is the slip of the motor at full load, which is usually about two to four per cent, and with such speed or any higher speed you can get all the torque you want.

Mr. Selleck seems to be rather opposed to alternating-current motors, especially on the ground that the equipment becomes rather heavy. He mentioned himself that a part of the weight was due to the compressed air outfit. That, of course, is not caused by alternating-current—it might be used in one case or the other either alternating-current or direct-current. I believe that the motor-generator set eventually can be reduced in size. Of course, as in anything else, a thing that you work out for the first time you work to safer limits, you allow a greater margin of safety, than you do after you have gained greater experience. I believe eventually the difference between the alternating-current and direct-current weight will be very small.

Wilfred Sykes: I will question one point raised by Mr. Selleck, and that is the regulation of the low-voltage distribution. He gave 10 volts. That corresponds to about 2.5 per cent. I have generally found that there is that drop in the transformer alone, without taking into consideration the lines.

Albert Kingsbury: It was my fortune, some nine or ten years ago, to have to make a report on the feasibility of using alternating-current motors in a coal handling plant. The report was made in reference to a large plant on Lake Superior, in which an attempt had previously been made to utilize alternating-current motors instead of steam engines. In discussing this question with the superintendent of the plant I found that he was very strongly opposed to the alternating-current motor. He told me that they had tried motors of the internal resistance type, not the wound rotor type, and he found that the motors heated very badly, and that the brakes gave trouble. The heating of the motors and the brakes was so serious that the electric drive was abandoned and replaced by steam engines. Nevertheless, I reported that it was entirely feasible to operate the plant with induction motors, and I have now the somewhat doubtful satisfaction of being able to say "I told you so."

J. B. Crane: Most of the questions that have been asked seem to have been answered by succeeding speakers, but there are one or two things I would like to speak about. Mr. Sykes brought up the fact that dynamic braking was not as expensive as the mechanical braking. My figures on that point were secured from a company that had both systems in use, and they said that the mechanical braking was cheaper. Mr. Sykes says that it costs about $4 a month to replace the parts of the mechanical brake, while the superintendent of the dock where this system has been in use three years, and where they first started out using wooden blocks and changed to asbestos blocks, told me the asbestos blocks lasted from a year to a year and a half, and that is the only expense they have had in connection with replacement.

On this dock, which has been in use three years, and was the first dock to install alternating-current motors at the head of the Lakes, there was no air whatever for operating clutches or anything else. Everything was controlled by alternating current, and there was not any direct current about the dock in any way. They were so very enthusiastic about it that when they put in the new bridge this last year they would not consider anything else, and wanted the bridge exactly the same except that, because they wanted to handle more coal, they put in a larger bucket.

I want to say from personal observation of the fact, in going around to the different docks, that the man in charge of the electrical equipment of that particular dock can always be found around the office, whereas going to other docks the man in charge of the electrical equipment is always on the bridge attending to trouble.

In regard to the air controlled system, we had this year fifty-six days in which the temperature did not go above zero. During that time they had considerable trouble with the water freezing in the pipes. We finally put a little alcohol in the pipes, and that seems to cut down the trouble from that source.

In regard to the method of charging and getting the peaks with the wattmeters, I would say that reliable and thorough wattmeters are not made for that kind of service. It is all right where you install it for an industry where the peaks are fairly steady, but on these instantaneous peaks it is hard to keep the wattmeter in condition, and there is trouble from overshooting.

We have made tests on several different makes of curve-drawing wattmeters and found that the overshooting varies from 20 to 60 per cent, depending on the extent of the peak, and also on the character of the load which is on when the peak starts. If you start from zero and go away across the scale, the overshooting will be 60 per cent. If you start from the middle of the scale and go across the overshooting will be only 20 per cent, and if you start a little higher it will be only 10 per cent. If you dampen your curve-drawing wattmeter to cut down the overshooting, the reading at the lower loads is wrong, and the errors on the lower loads will be anywhere from 20 to 40 per cent.

We have also made some tests with one of the printing attachments to integrate the peak, and we find that the integrated 5-minute peaks, when the peaks are in full operation, amount to practically the same as 40 per cent of the instantaneous peak, and it is possible we will adopt some other method in connection with this peak charge. When we first started in we had considerable trouble with the dock owners owing to this instantaneous peak, but that has practically been eliminated from the fact that we do not take the highest instantaneous peak each month, but take probably the fourth or fifth highest.

In regard to the discussion of alternating current versus direct current, and the fact that a new direct-current dock was going

into operation at Duluth this year, I would say that while the owner of that dock has already an alternating-current dock in service, his adoption of the direct current was more on account of the fact that he is entirely opposed to alternating-current motors for any sort of use. He operates a coal mine and has had considerable experience with direct-current motors, and he says he would not have an alternating-current motor under any consideration. So the direct-current motor was adopted in that case simply on account of the fact that the owner is unalterably set against the alternating-current motor, rather than because the operators of the machinery consider the direct-current motor much superior for the operation of the dock.

The other direct-current apparatus going in is being installed on docks already equipped with direct current, so, of course, there is no reason why they should change to alternating current. As it happens, there are two alternating-current docks going into operation this year, and they will be as large as any other docks at that point.

The slowing down of the operation of the dynamic brake before the bucket reaches its lowest point is exactly the same thing that the owners of the coal dock want to get away from. They want to run at the topmost speed until they get to the end and then want to stop immediately. That is the way they run the apparatus—they do not want to slow down and wait until they get to the end of the travel before stopping, and of course, that is why they are very hard on the motors.

The criticism has been made that the current consumption was high. The figures of current consumption were secured by taking the total kw-hr. consumption for the year and dividing that by the number of tons of coal that was sent out from that dock. That includes unloading the coal, and includes overhauling the coal—most of these docks have fires during the year, and when they have fires the men have to get down with the buckets and simply dig out the fire; that figure also includes the consumption of the car loaders and all the other apparatus about the dock.

The figures for the actual unloading of coal from the boat to the dock only, will vary, as Mr. Sykes said, from 0.35 to 0.6 kw-hr. per ton of coal, depending on how far the coal is taken back on the dock.

There has been but one serious accident on account of shock. One man was killed by getting on top of one of the hard coal sheds where the 13,000-volt line runs along on top of the shed, and he came in contact with the 13,000-volt wire and was killed.

In regard to taking coal up to the dock and lowering it to the dock, answering Mr. Friedlaender's question, the coal has to be lowered to avoid breakage; it cannot be dropped like ore. As soon as they get a pile started they keep unloading on the side of the pile, so that they do not have to lower the coal right down to the dock proper.

Regarding the breakage and loss in value of the coal, two of the docks at the present time have installed briquette plants, and they are making a success of briquetting the coal dust, which was formerly wasted, or for which they obtained only a very low price. A few years ago the coal dust was used for filling and practically thrown away, but gradually it came up in value from 20 cents a ton until now it sells at $1.90 a ton, and briquetted it sells for about $4 a ton.

There is always some breakage of coal due to the jaws closing on the coal in the hold of the boat, but that is one of the things that it seems impossible to guard against.

Considering the cost of installing 220- and 550-volt direct current as compared with 440- and 13,000-volt alternating current, I think the man who made the calculations must be mistaken. He gives 13,000-volt system as the highest in cost. Several other companies that have made these calculations have found the 13,000-volt distribution very much cheaper.

The speed of operation is, of course, a very important point to the operators. In the car-equipped dock the buckets are only of 2.5 tons capacity, and the bucket makes 2.5 trips per minute. The operators have to work pretty hard all day long, and it is impossible to speed them up any more, because they simply cannot operate any faster. On the other hand, on the man-trolley docks, the operators only have to handle it about one and one-half trips per minute, and there is the chance of speeding them up if they can get apparatus that they can handle faster.

If Mr. Kingsbury could come to the head of the Lakes at the present time I am sure that he would agree that his predictions have been fulfilled in respect to alternating-current motors—that coal dock operation with them is certainly a success.

DISCUSSION ON "THE OPERATION OF A LARGE ELECTRICALLY DRIVEN REVERSING ROLLING MILL." (SYKES) PITTSBURGH, PA., APRIL 26, 1912. (SEE PROCEEDINGS FOR MAY, 1912).

(Subject to final revision for the Transactions.)

R. A. Black: The discussion has been on electrically operated rolling mills. A question comes to my mind as to the comparative cost of electrically operated versus steam operated mills. This is one thing that electrical engineers are facing now, the question of which pays. I heard the superintendent of a large steel mill say recently that this subject has never been taken up and thoroughly discussed, and that he had never been able to find any comparison of the cost of operating an electrical mill and a steam driven mill. Is it better? Is it cheaper? Does it pay to operate electrically? Which is the more flexible? Can you turn out steel as quickly and as economically with electric as with steam operated mills?

As I understand the construction of the electrically operated reversing mills, there is a motor-generator set with a heavy flywheel between the switchboard and the mill motor which takes all undue stress from the switchboard, this being accomplished by the energy stored in the flywheel. Is there any particular kind of steel mill service that steam is better adapted to than electric drive? For instance in bar, billet, slab, or plate mills, would steam be better on some and electricity for others?

H. C. Specht: I wish to ask the question in which case it is right to use a reversing mill and which case a three-high mill. The difficulty of the three-high mill is well known among steel men. As we have a number of steel engineers in this meeting, it would probably be very interesting to hear how serious the difficulties of the three-high mill are and if there is really in all cases enough reason to use the two-high reversing mill, instead of the three-high mill. From the electrical point of view, the three-high mill would work more economically than the two-high reversing mill. The overall working efficiency of large motors on a three-high mill is generally at least 86 per cent, whereas, with a two-high reversing mill it probably would not exceed 64 per cent.

R. Tschentscher: The questions which Mr. Specht has asked in connection with the relative economy of the three-high versus the two-high mill, was discussed by me at quite considerable length at the Chicago meeting of the American Institute of Electrical Engineers, in connection with Mr. Sykes paper, and I think covers about all I have to say on the subject. There is quite a difference of opinion on the subject. Mr. Specht mentioned 86 per cent on the three-high mill versus 64 per cent on the two-high mill. I think that can be immediately dismissed after it is stated. There are so many factors which enter into the proposition, that efficiency is really a term which can only be mentioned in connection with the full load operation. There

are many other questions of mill practise that enter into the rolling, which are of much more vital importance than the mere statement of the relative efficiency of the electrical equipment. One equipment with a full load efficiency of 60 per cent may be a more economical outfit than an equipment having a full load efficiency of, perhaps, 90 per cent.

All these problems, from my point of view, are local problems. The question of steam operation versus electrical operation is a local problem. If the cost of fuel, the cost of getting power is low, at the mill,—I am speaking now of steam power—it is possible that a steam driven mill may be the more economical to put in. If the local mill is at some distance from what is considered a waste product in the steel plant, for instance, blast furnace gas, there seems to be no question but that electrical drive is the more economical. The questions of up-keep, the questions of steel supply, the questions of the output of the particular plant involved, all must be taken into consideration.

Mr. Specht asked the question as to whether the electrical reversing mill was better adapted for one class of output than another. I went into that subject quite carefully to the extent of obtaining the opinion of men who are considered high grade rolling mill men, and I believe that the consensus of opinion is that a three-high mill will give a larger total output for billets than a two-high mill, but for plates a two-high mill will produce a larger output, and in many cases a better quality of output.

The question of quality is now of as much, if not more, importance, than the question of output. If we can obtain better quality by the use of the two-high mill, with its graduated speed control, that is a factor which is going to appeal to rolling mill managers much more than it has in the past. We do not hear so much of the word "tonnage" now as we did six or seven years ago. The question of safety brings in the point of voltage and the question of quality.

James Farrington: I ask Mr. Tschentscher to express his opinion of the two-high mill, relative to the three-high mill, as to the cost of upkeep, if he has that information.

R. Tschentscher: There have not been enough data available from a three-high mill, electrically driven, versus the two-high mill, electrically driven, from the standpoint of the up-keep of the mill equipment, to give anything definite; but a comparison between two-high and three-high mills steam driven leaves no question as to the relative cost of up-keep. I think one of the biggest points in the three-high versus the two-high electrically driven mill is the fact that the two-high mill can be shut down instantly, and that there will be a great many more minor repairs made in the case of the two-high mill than in the case of the three-high mill. In the three-high mill shutting down or starting up involves considerable delay, and those small troubles which may come up, which are corrected in the two-high mill, are left in the three-high mill until they assume considerable magnitude,

before they are given attention, resulting in more expense and greater delay.

Bradley T. McCormick: This paper is very interesting, but as most of the data it contains is in the form of figures it will require considerable study for anyone to enter into an intelligent discussion of it.

However, I will ask what has been found to be the variation in speed of the motor-generator set, between its highest and its lowest speed, under normal rolling conditions?

E. Friedlaender: With regard to reversing mills and straight-running mills with flywheels I would like to make a few remarks. The reversing mill is used in Europe much more than it is in this country, as rolls can be arranged for a number of different sections. In Europe they do not run on straight work for days and weeks, and as they change probably two or three times a day, the reversing mill is much handier, thus saving thousands of dollars on rolls which would be necessary on the straight running mill, for different products. When a mill is designed for certain products and runs probably most of the time on the same product, a three-high mill is preferable and I think in the future the reversing mill will not be used as much in this country as in Europe; and, as has been shown in recent installations, a compound condensing steam engine with flywheel direct connected to the roll will be hard to beat in cost compared with electric generators at the power house, transmitting the power, say, half or a quarter of a mile, at high tension, and going through motor generator or direct to the motor, unless the power is generated at a very low cost without the use of steam. In the Pittsburgh district we have generated power at a very low cost, and have found out that in considering only the operation and repair of the motor, that electrically driven mills are cheaper to operate, but considering the repairs to the total installation, it is very hard to beat the modern compound condensing steam engine supplied with a flywheel.

A paper presented at the Philadelphia Section Meeting of The American Institute of Electrical Engineers, Philadelphia, Pa., April 8, 1911.

(*Subject to final revision for the Transactions.*)

SOME FEATURES OF THE OUTDOOR ELECTRICAL INSTALLATION

BY F. C. GREEN

Economy in the construction and operation of power systems is engaging the best thought of engineers with the purpose of making the systems attractive to investors, as well as to those who utilize the power. The outdoor installation is based principally on economy in construction and partly on economy in operation.

The presentation of a previous paper* on this subject, was the occasion of much discussion by eminent engineers. Many of the details of construction and operation were gone into. The idea was indorsed by some and opposed by others, while in the main the discussion was mildly favorable. It was generally agreed that the principal consideration is economy. Some careful figures made for small substations show a net saving of 10 to 30 per cent over the indoor installation. At that time the outdoor installation was limited to transformers of small capacity except some 500 kv-a. 60,000-volt transformers that had just been installed. According to the general opinion expressed, the principal difficulty was to prevent moisture from getting into the outdoor transformers and switches. The extra cost of making them water-proof and air-proof was estimated to be from 6 per cent to 8 per cent. There was some difference of opinion as to whether life and property hazard, and convenience of operation would be seriously different from these features of indoor stations. Most of the discussion was based

High Voltage Transformers and Protective and Controlling Apparatus for Outdoor Installation,* by K. C. Randall, TRANSACTIONS A. I. E. E. **1909. Vol. XXVIII, page 189.

upon more or less apparently well grounded opinion, practically no experience being given.

List of Transformers. Following are the ratings of some transformers built for outdoor operation, since the presentation and discussion of the 1909 paper:

LOCATION	NO.	RATING
North Carolina	3	60–140–22,000
New York	1	60–150–16,500
North Carolina	3	60–300–18,480
Pennsylvania	4	60–150–33,000Y
North Carolina	3	60–150–22,000
Minnesota	1	60–150–66,000
Minnesota	6	60–200–33,000
North Carolina	3	60–200–22,000
North Carolina	3	60–200–44,000
North Carolina	3	60–500–50,000
North Carolina	3	60–500–22,000
California	3	60–200–66,000
Tennessee	3	60–200–66,000Y
California	3	60–300–66,000
Alabama	3	60–300–66,000
Montana	2	60–200–50,000
Montana	1	60–200–50,000
North Carolina	4	60–2750–100,000
Georgia	6	60–3333–110,000
Georgia	9	60–1000–110,000
Florida	3	60– 667– 62,400
Florida	7	60– 500– 33,000

In numerous transmission systems, high-tension oil switches and lightning arresters are installed outside. In several substations, transformers, as well as high-tension and low tension-buses are outdoors.

Types of Indoor Construction

Thus we find the extensiveness with which the idea is being put into practice, warrants further consideration of the advantages and disadvantages involved. A study of the principal factors of economy seems to lead to the conclusion that a greater percentage of saving may be expected than the values given in the previous paper and its discussion; and that the idea may be profitably extended to the installation of oil switches, buses and transformers outdoors for both substations and power stations,

excepting those where conditions make it imperative to have them indoors. It is believed that a review of the existing conditions as embodied in the whole practice of generating, transmitting and distributing electrical power, will prove more valuable in arriving at correct conclusions than the making of detail estimates for the requirements of any given and limited application of the idea.

As related to the subject, there are two general types of housing construction for electrical apparatus; the open housing and the compartment housing. The open housing type includes those stations where most or all the apparatus and buses are not installed in individual compartments, but in open spaces. The compartment housing type includes those where most or all of the apparatus and buses are installed in individual compartments. In existing installations the two types of housing are pretty well balanced.

In the compartment power station, approximately 60 per cent of the ground space is required for transformers, buses, switches and lightning arresters. From mere observation of these plants it can be seen that the cost of the compartment construction is at least equal that of the housing including the foundation, for the apparatus and buses specified. Also the substantial construction used in many of these buildings must result in a very considerable percentage of the cost of the apparatus and buses being consumed in the cost of the portion of the building and compartments occupied by them; and this percentage represents a considerable percentage of the cost of the whole plant. The amount of saving effected would be greatest in the compartment type of station. In the open type of station, the saving would decrease from those having part of the apparatus and buses enclosed, to a minimum with those having only the outside walls.

Outside Installation at Generating Station

It frequently happens that the location of hydroelectric power houses necessitates large expenditures for building foundations. The outdoor installation admits of using any convenient space nearby and would effect considerable saving above the amount estimated for more favorable locations.

The Outdoor Substation

The substation repair house would serve as panel room for control switches, in case the substation was of sufficient size to war-

rant having a repair house. Where substations are used for supplying mills they may be located sufficiently close to the mills to make it unnecessary to have a special repair house and operating room. Part of the mill building may be used for these purposes. Electrical railway stations require sufficient housing for the revolving apparatus and control panels. Also there should be sufficient room in the building to have a transformer repaired. For very small repair houses arrangements can be made just outside of the house for taking the transformer out of the tank, in order to avoid so much head room inside. This is a common practice with at least one large power company, which has a great number of indoor substations. A simple wood or steel structure is erected just outside of the station. A device for lifting is provided, and it may be transported from one substation to another.

Where the substation embodies much apparatus it is advisable to provide ample facilities for shifting the apparatus around. For instance, if a transformer should fail the facilities ought to be sufficient to admit of its being readily transported to the repair house, and if necessary, another transformer moved into its place. Tracks should be laid so that any transformer in the installation can be readily transferred from its operating position to the repair house, by means of a truck. For small substations where a repair house is provided, it can be located close to the transformer installation. Heavy timbers may be used for a track on which to roll the transformer. In fact, except for the very largest sizes, transformers can be more easily handled with pipe rollers on timbers than with the elaborate wheel construction and the necessary rails.

Moisture

We now come to those features of the details of apparatus upon which the whole question of the success or failure of the outdoor installation depends. In the previous paper and its discussion, it was quite clearly brought out that the most vital question is whether transformers, switches and lightning arresters can be built so as to be weather-proof. Since a considerable amount of this apparatus is already operating out of doors, it is only a question of the elapse of sufficient time to prove failure or success. Experience with small transformers that have been located on poles, indicates that there is not as much danger from moisture as is feared by those who have discussed this

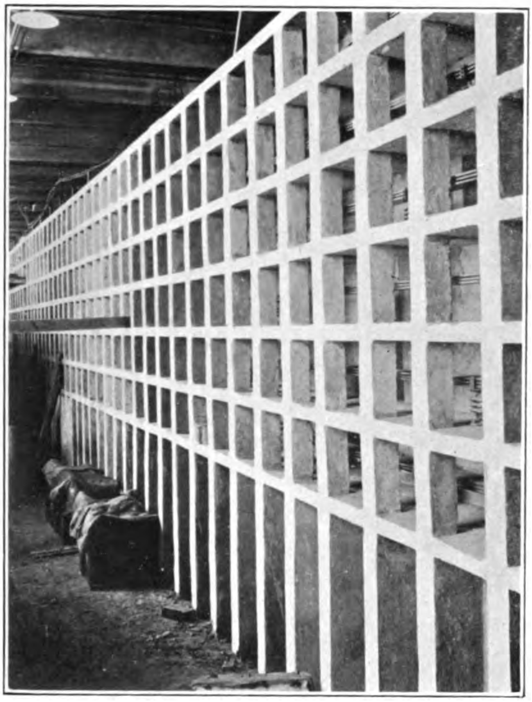


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FIG. 1—SHOWING CONSTRUCTION OF GENERATOR BUS COMPARTMENTS.

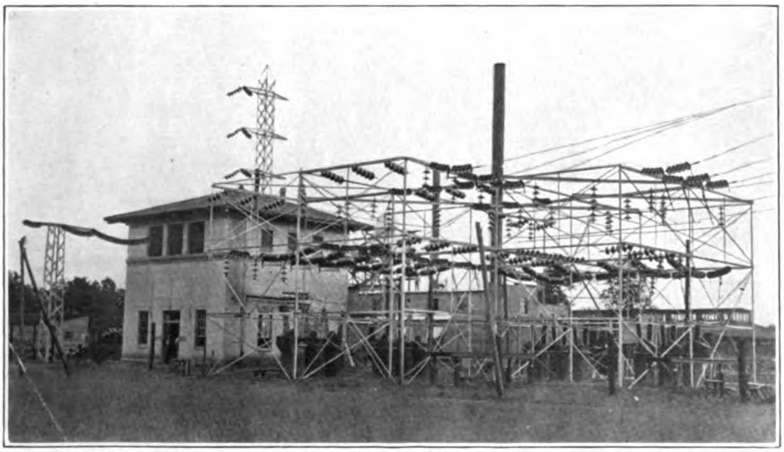

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FIG. 2—OUTDOOR INSTALLATION OF OIL SWITCHES AND BUSES FOR 100,000-VOLT SERVICE.

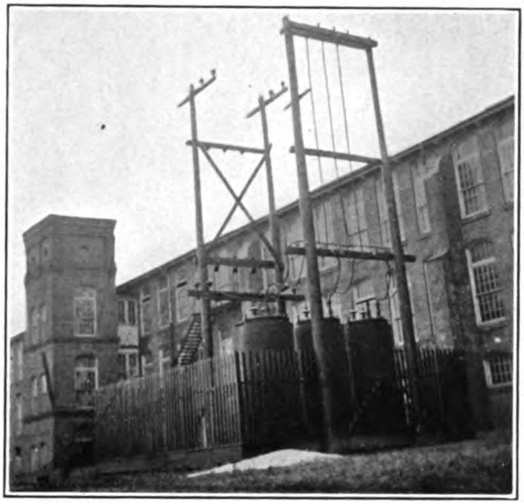

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FIG. 3—OUTDOOR INSTALLATION OF 100,000-VOLT TRANSFORMERS.

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FIG. 4—OUTDOOR INSTALLATION OF 100,000-VOLT TRANSFORMERS.

feature. Out of 74 transformers, 1 to 25 kv-a. in size, that had been in service two to five years, near the seashore, where the moisture conditions are considered unusually severe, samples of oil were drawn and tested. The puncture voltage obtained between ½-in. copper disks, 0.2 in. apart, ranged between 25,000 volts and 44,000 volts. These values do not show that any moisture got into the oil, notwithstanding that many of the transformers were idle during a considerable period of each winter. Transformers used for pole suspension have never been made air tight, most of them in fact being provided with a breathing space in the gasket between the cover and tank.

On the other hand, practise has shown that in some instances, indoor installations are subject to atmospheric conditions that admit very serious condensation, inside of the transformer cover. In those instances where serious condensation has taken place, no special provision was made either to make the cover air tight or to give it a breathing space. Thus we find that practise seems to show a paradox as far as opinions that have been given are concerned, but, if a careful analysis is made of the conditions involved, the facts are not so surprising.

The weight of water per cubic foot of air is nearly always greater in buildings than outdoors, except during periods of rain. This statement is based upon the facts that temperatures inside of buildings are higher, which admits of the air carrying more moisture; buildings are occupied by people whose breathing tends to increase the humidity; water may be exposed in the buildings in such a way as to increase the humidity. Transformer stations are rarely specially heated, with a view to making them comfortable; still as a rule they are kept at a higher temperature than the outdoors. In such stations, and in transformers that are not especially ventilated or especially tight, changes in temperature conditions are not followed by an immediate readjustment of pressure conditions. That is, the air in the station and in the top of the transformer, having no free and easy path to follow, will assume the temperature change without immediately assuming the corresponding pressure change; which condition, in case the temperature is lowered, results in condensation, especially considering that the enclosed air is liable to have more water per cu. ft. than the outside air. With the transformer out of doors, and with proper breathing space so arranged that neither mist nor rain can get inside, the atmospheric conditions are free to assume immediately any change in temperature or

pressure in the air outside. It, therefore, seems safe to conclude that there is little chance of condensation inside the top of a transformer located out of doors, and with a protected breathing path provided.

TABLE 1.

Pounds of water necessary to saturate 1310 lb. (594.206 kg.) of air (18,000 cu. ft. at 25 deg. cent.) at various temperatures; atmospheric pressure.

Degrees cent.	Pounds Water	Kilograms
22.2	23	10.4
27.7	32	14.5
33.3	44	19.9
38.9	61	27.6
44.4	84	38.1
50.0	115	52.1
55.5	158	71.6
61.1	217	98.4
66.6	302	136.9
72.1	426	193.2
77.7	622	282.1
88.8	1650	748.4
94.3	3760	1705.5

However, if a more extensive practise should disclose that condensation is found occasionally, the most satisfactory means of preventing this would seem to be the introduction of a very small heating coil in the top of the transformer; a free breathing path still being retained. A lining of heat insulating material on the inside surface of the cover, would tend to retain the heat and to prevent condenstation. A very slight increase in the temperature of the air in the top of the transformer will have the desired effect. The attachment of drying breathers to the transformer is unsatisfactory in several respects. The material used for drying the air tends to throttle the circulation and free exchange. The care required in keeping the breathers in good condition is objectionable. They are cumbersome. To make tanks air tight is difficult and expensive. Unless they are absolutely tight the condition inside the top of the transformer will be favorable for condensation. The same facts and reasoning advanced in connection with the transformers, apply for the construction of lightning arresters, and oil switches.

DIRECT HEAT FROM THE SUN

The prevention of the transformer's absorbing the heat from the sun in the summer time is a problem easily solved. By placing around each transformer a cylinder of some simple heat insulating material which may be inappreciable in expense,

we not only get rid of the heat from the rays of the sun, but slightly increase the cooling, due to the chimney effect. It has been found that sheet metal, with the surface next to the apparatus, painted white, makes an effective screen.

Types of Transformers for Outdoor Installations

Air-Blast Transformers. Air blast transformers can easily be adapted for outdoor operation. The intake of the blower and the space where the air is discharged from the transformer can be so constructed, with little additional cost, as to prevent the entrance of rain into the windings. There is no question of the effects of the direct heat of the sun or of freezing. Moreover, assuming that a small amount of rain should be drawn in through the blower, the effect would not be serious; the higher temperature of the air would give it so much greater capacity for moisture that the rain would be absorbed by the air and carried away. (See Table 1).

Water-Cooled Transformers. In the use of water-cooled transformers provision must be made for preventing the freezing of the water in the circulating piping and in the cooling coil. The cooling coil should have its terminals brought out at the bottom of the transformer and the piping either run under ground to the sources of supply and drainage, or heavily lagged if the piping is run above the ground. The piping should be so laid that it can be drained when it is not necessary to circulate the water. The critical situation as regards freezing occurs when the transformer is held idle. These occasions rarely exist, except where a spare is held. In order to take care of an emergency, space for an electric heating coil can be provided under each transformer, in order that the coil may be put in position when necessary.

Oil-Cooled Transformers. What will probably prove the most satisfactory type of transformer for outdoor operation is the oil-cooled type, which requires no auxiliary cooling apparatus, and the least attention in service. By means of the cylinder placed around the transformer to shield it from the direct heat of the sun, the natural circulation of the air is slightly increased. There is ample supply of fresh air. In discussing this subject it may be well to refer to the use of large, self-cooled, units for indoor stations. A number of such units are now in service but have not operated sufficiently long to determine the vital question of heat under the conditions. Judging from the little attention

that has been given to ventilating stations where oil-cooled transformers are installed, and from the temperatures that have resulted, it will not be surprising to find that the very large units cause the temperature of the buildings in which they are installed to become dangerously high. Assuming the installation of three 2000-kv-a. units in a building of the usual construction and size, we find that under full load approximately 120 kw. of energy must be dissipated. Twenty-two thousand cubic feet (623 cu. m.) of air per minute would have its temperature raised ten degrees by this amount of energy; or, a building approximately 40 ft. by 20 ft. by 27 ft. (12.2 by 6.1 by 8.2 m.) high would require having its air entirely renewed once every minute in order to prevent a rise greater than 10 deg. cent. in the room temperature. In order to prevent undue station temperatures it is necessary either to have artificial circulation of the air through the building, or to have the building unusually well ventilated.

Prevention of the freezing of the oil in case a transformer should be held out of service, can be effected by means of an electric heating coil placed beneath the transformer. However, experience has shown that there is no particular danger in the freezing of oil; also certain grades of transformer oil do not freeze at temperatures as low as minus 40 deg. cent.

Installing

Installing high voltage transformers involves considerable expense and time. Where they are shipped with oil in them, the operation of installing is reduced merely to placing the transformer in position and connecting in circuit. This procedure has the disadvantage that the transformers are more difficult to handle, and according to the practice that has been followed, no inspection is made of the internal parts to determine whether they have been disarranged in shipment. Therefore, for the present at least, the great majority of transformers must be put through a drying process.

There are three general methods used for drying transformers. One that has been used the most and the longest is the circulation of current through the transformer windings with one of them short-circuited and sufficient voltage impressed upon the other to give the desired value of current. In applying this method the transformer may be outside of the tank or inside, with at least the manhole cover removed and with any opening

in the base that is convenient. This method is now little used, principally for the reason that with high voltage transformers the insulation between windings and between winding and iron, is so great as to place most of it practically out of the range of the effect of the heat generated in the coils. Also, notwithstanding that it has been used so long, it requires great care in its application to prevent damage to the transformers from excessive current.

Another objection to the use of this method where a transformer has been exposed to unusually severe conditions of moisture, is that in shell type transformers practically no heat extends to the punchings of which the core is built. A surprising amount of water is sometimes found between punchings. This water is not immediately dangerous, assuming the coils and insulation to be dry, for the reason that when it is driven out in service, it usually gravitates towards the bottom; but its presence has been responsible for mysterious accumulations of moisture in the bottom of transformers after they are put in service.

The vacuum method is the second oldest method. Under this method the transformer is put under the short circuit run and its tank made vacuum tight. The windings are usually run at a temperature of from 80 to 90 deg. cent. and the tank is held under a vacuum ranging between 20 and 28 in. (50.8 and 70.8 cm.). To obtain good results it is necessary to have a high degree of vacuum, for the reason that the temperature is so very uneven throughout the transformer structure.

TABLE 2.

TABLE OF BOILING POINTS OF WATER

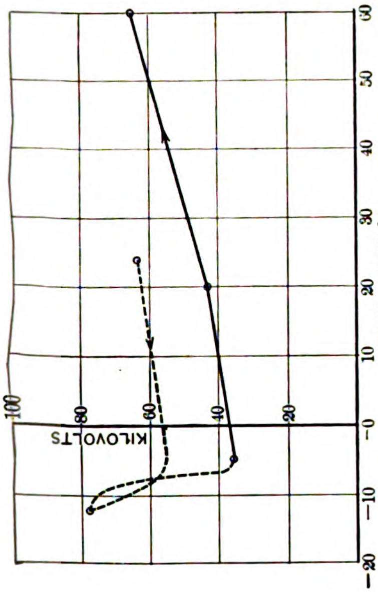
Degrees cent.	Inches vacuum	Centimeters
5	29.7	75.3
10	29.6	75.1
15	29.5	74.8
20	29.4	74.6
25	29.0	73.6
30	28.7	72.9
35	28.3	71.0
40	27.8	70.5
45	27.1	68.7
50	26.3	66.6
55	25.3	64.1
60	24.1	61.0
65	22.6	56.5
70	21.1	52.2
75	18.6	46.5
80	15.9	39.2
85	12.9	32.2
90	9.2	22.5
95	5.0	12.7
100	0.0	00.0

Under the vacuum practically only radiation gives distribution of heat, as there is no circulating medium for distributing it. The coils, where the heat is generated, are hottest; but the insulation between high tension and low tension windings and between the windings and iron, upon which the transformer must rely for its strength, does not reach a sufficiently high temperature to bring it within the limits of temperature and vacuum necessary to cause the moisture to vaporize. All of those parts that do come within such limits are made dry. Furthermore it is rare that a transformer is built upon such close margins that even a small amount of drying will not prevent its breaking down under normal operating conditions. Unless the transformer tank and cover are made especially tight, it is difficult to obtain the necessary vacuum. All around, the most satisfactory method of drying is the circulation of large quantities of heated air through the transformer. This method gives practically uniform temperature throughout the transformer structure and does not require a skilled electrical operator. A unit consisting of electrical heater, small blower and motor has been developed which is light and cheap.

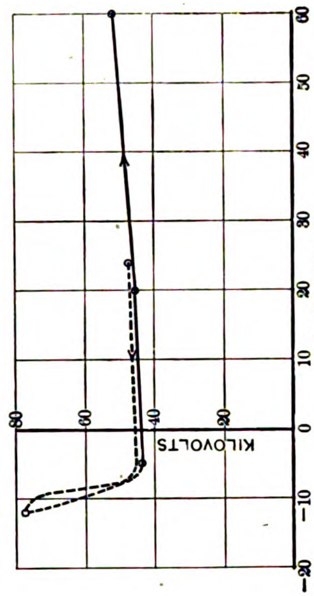
One of the problems of the outdoor installation, apparently difficult to be taken care of, is a place to put the transformers while they are being dried. Probably not more than one at a time can be placed in the repair house. For this reason it is necessary to consider drying them in position out of doors. Assuming heated air to be circulated for drying, there does not seem to be any objection to making the cover water tight and piping the outlet from the cover in such a way as to prevent the entrance of rain. Also temporary housing can be placed over the intake of the blower.

Only a few years ago not much attention was given to drying out transformers, but in later years very close attention has been given. Formerly transformers failed occasionally between high tension and low tension windings and between windings and iron, which was a pretty good indication of moisture; but latterly, since the use of more care in installing, there have been practically no such failures.

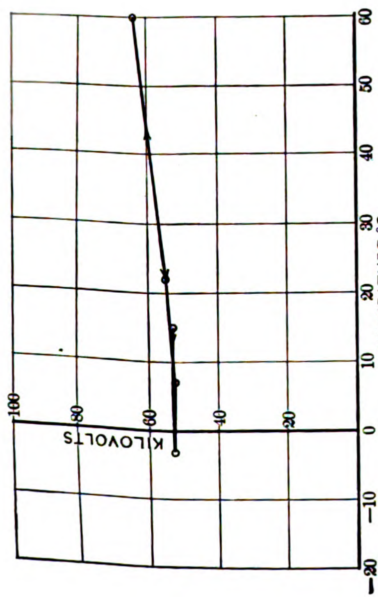
The problem of drying oil has been a difficult one to solve. Numerous methods have been used. The principal ones are: forcing hot air through oil under high temperature; heating the oil to a sufficiently high temperature to cause the moisture to vapor-



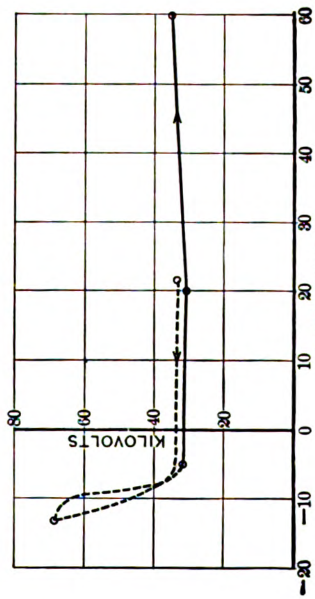
Curve 2.—No. 8 Transil Oil



Curve 4.—No. 6 Transil Oil



Curve 1.—No. 7 Low Cold Test Oil



Curve 3.—No. 10 Transil Oil

Dielectric Strength of Oil at Various Temperatures

Oil Spark Gap, ½-in. disks, 0.2 in. apart

ize; heating the oil sufficiently to produce vaporization of the moisture with the oil under vacuum; forcing the oil through chloride of calcium, or lime, and sand; forcing the oil through dry blotting paper. The filtering methods are used mostly now. The blotting paper filter has proved most satisfactory. The paper constitutes a reliable and convenient filtering material with which oil may be treated to withstand a puncture voltage of 40,000 to 50,000 volts between ½-in. (12.7 mm.) disks 0.2 in. (5 mm.) apart. The necessity of heating the oil, which is always dangerous and injurious, is eliminated. All foreign matter, such as sediment and scale, as well as moisture, is removed.

Operating

If the planning and building of power plants have been characterized by the extravagance of too liberal consideration, it can be said of operating that there has been equal or greater extravagance in the absence of thoughtful consideration of any kind. Whether the power plants throughout the country can be said to represent good business judgment along lines of economy, may be questioned by some. On the other hand it is only within the very recent past that even in the most progressive and extensive power systems, much attention is given to operating features. Efforts along operating lines have been confined to those activities necessary in keeping the system going, and not much thought has been directed towards the prevention of accidents that interfere with service.

The consideration of effective economy is forcing the realization that there is much opportunity for saving, in guarding against conditions which have a tendency to bring about preventable trouble. In the past, commutators have been wiped and occasionally turned down; the dust has been blown from revolving machinery; bearings have been oiled. The time is now in sight when, in addition to these necessary and ancient operations, the right switch will be closed in the right order; oil in transformers, lightning arresters and switches, will be periodically inspected and treated when necessary; transformers will be inspected and cleaned; they will be kept cool; numerous other operating features that involve possibility of much accidental loss, will be duly considered.

There is no question that much extravagance has resulted from inattention to transformers in service. They are designed and built for a given temperature rise ranging between 30 and

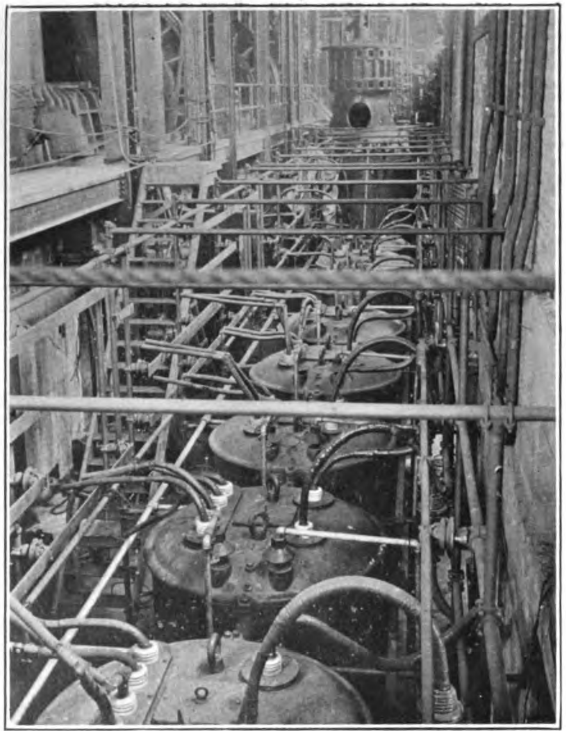


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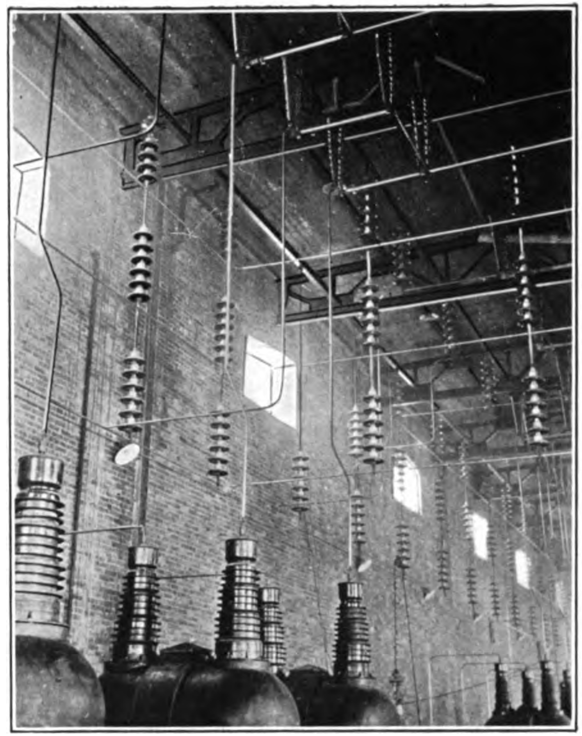
FIG. 5—OPEN TYPE OF TRANSFORMER INSTALLATION IN CLOSE QUARTERS.



[GREEN]

FIG. 6—OPEN TYPE OF INSTALLATION—100,000-VOLT BUSES AND SWITCHES.

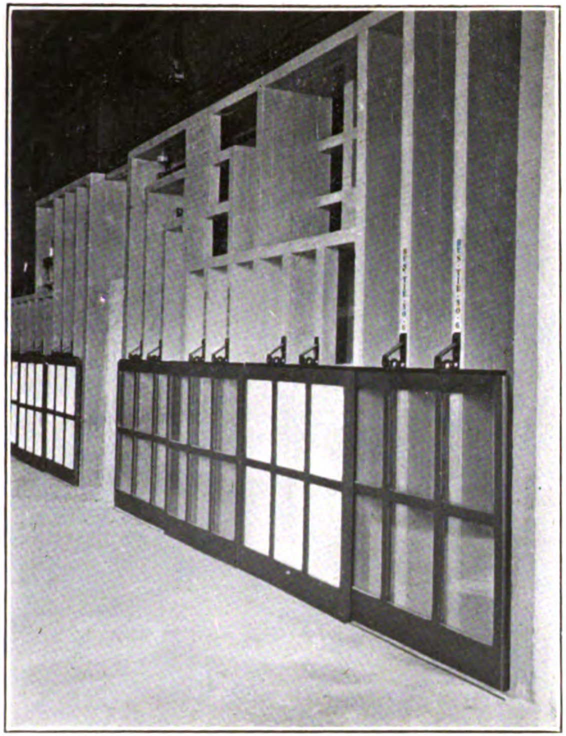


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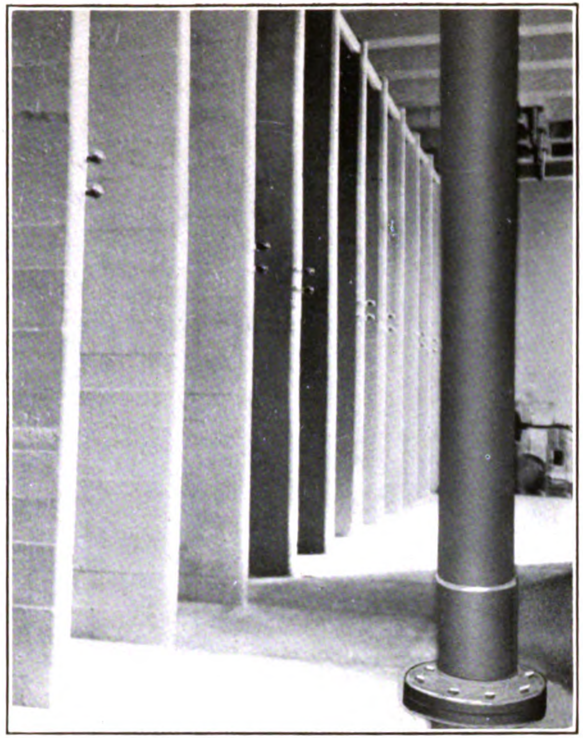
FIG. 7—COMPARTMENT TYPE OF INSTALLATION—GENERATOR BUS COMPARTMENTS.



[GREEN]

FIG. 8—COMPARTMENT TYPE OF INSTALLATION—HIGH-VOLTAGE BUS COMPARTMENTS.

50 deg. cent., but these limits have been used simply as standards for purchasing and not for operating. The cooling coils of water-cooled transformers have been allowed to become lined inside with foreign substance, or the section of the cooling coil has been restricted by the residue of chemical action between the water and the cooling coil. Water has been allowed to become heated or too small in quantity. All of these conditions tend to cause the oil in the transformer to heat excessively, which results in deposit on the surfaces of the cooling coil and on the surfaces of the parts in which the heat is generated. The efficiency of the cooling coil becomes very low, the transformer deteriorates and finally breaks down for some "unknown" reason. In the case of the oil-cooled transformers, buildings are not properly ventilated. The oil heats excessively and throws down deposit, which is an excellent insulator of heat. The temperatures run higher and higher and finally the insulating material becomes weakened.

To obtain a more comprehensive view of the importance of the situation, we will assume a transformer for high tension transmission, so built as to easily withstand in its normal condition, the usual amount of high voltage disburbances. Let us assume that the ordinary procedure is followed in the operation of the transformer, which means that practically no attention is given it. For reasons which nearly always exist, heat begins to cause a deposit from the oil. This deposit settles on surfaces and prevents sufficient cooling. The transformer lasts perhaps five years to fifteen years, depending upon the severity of the heating and of the operating conditions. This represents the true story of the life of a great many transformers.

There does not apear to be any sufficient reason why the life of a transformer should not be indefinitely long. It is only a question of attention to prevent the conditions that result in a short life. It is evident that even the effects of long continued mild heating, must be taken care of. It is imperative that excessive heating be prevented, if the possibility of length of life is to be taken advantage of. Moreover it is obvious that the period of the summer months is the one in which the mischief is done. Air and water used for cooling transformers are much hotter in the summer time than during the rest of the year. Therefore, the problem comes down to taking care of the cooling during the summer months.

The most attractive proposition seems to be the adoption of

the oil-cooled unit for the outdoor installation. It is built for the ordinary temperature rise of 40 deg. Installed, it has around it the cylinder of insulating material which has been referred to. This cylinder not only keeps off the direct heat of the sun but slightly increases the circulation of air. Under these conditions the temperature would not be excessive during nine months of the year, but the other three months are the critical period. To take care of this period, an electrically driven blower is used to produce artificial circulation between the insulating casing around the transformer, and the tank. Tests which have been made show that the capacity of the transformer can be easily increased 50 per cent for the same temperature rise. This extra capacity is ample to lower the temperature sufficiently in the summer time to prevent dangerous effects under normal loads. Running under these conditions, the oil should be noted at least twice a year and the transformer examined whenever the condition of the oil indicates the probable necessity.

For treating the oil while the transformer is in service, the filter press has been found to be highly satisfactory. All that is necessary is to attach the suction connection of the press outfit to the valve in the base of the transformer and pipe the discharge of the outfit to the connection for this purpose. Even when the best of care is taken of transformers, it is well to filter the oil at least once every two years, and in case any appreciable discoloration is noticed it should be filtered oftener. By thus keeping the oil clear of any deposit that may result from heating, the surfaces inside the transformer will be kept clean, and efficient in the dissipation of heat.

Summary

The principal advantage of the outdoor station is in lower first cost of plant. Another important advantage is that the layout may be enlarged or modified at a much less cost and inconvenience than an indoor station could be enlarged or modified for. There is less fire risk. The cooling of air-blast and oil-cooled transformers is more efficient.

Some apparent disadvantages are the installing of apparatus outdoors; the possibility of the entrance of moisture into the apparatus; handling apparatus outdoors in bad weather; meddling with the apparatus by trespassers.

According to the construction being adopted for the support of outside buses, there is no chance of a person's coming in

with the wiring unless he climbs upon the apparatus or
.e structures. All wiring is out of his reach. However,
ers can be kept out by building a fence around the in-
n.

ng from the experience, it will not be as difficult to keep
e out of the apparatus as it has seemed to be. In fact,
es not seem to be any very serious objection that cannot
come. Perhaps the one objection that will prove to
nost serious, is making temporary changes that may be
ied by unexpected accidents, in very bad weather.

is particularly true with regard to high-tension oil
s. On account of moving parts, they are more difficult
ect against the weather, and are therefore more liable
ire repairs resulting from weather conditions.

POWER REQUIREMENTS

OF

ROLLING MILLS

BY

WILFRED SYKES

Presented under the auspices of the

Industrial Power Committee

A paper to be presented at the 277th Meeting of the American Institute of Electrical Engineers, New York, November 8, 1912.

(*Subject to final revision for the Transactions.*)

POWER REQUIREMENTS OF ROLLING MILLS

BY WILFRED SYKES

The increasing use of electric motors for driving the main rolls in modern steel works, makes the question of the power requirements of rolling mills of considerable importance to the industrial engineer engaged in designing such installations. An error in judgment due either to inexperience or to lack of accurate information, may involve the loss of a large sum of money in the installation itself, but what is of still greater importance, is the loss that is incurred indirectly, due to the time lost before the error can be remedied.

The subject is one of great complexity due to the various factors controlling the power requirements and also to the variation in operating conditions in different works. The subject of rolling mills is one on which it is hardly possible to obtain reliable information from published data and the whole rolling mill practise is based upon empirical knowledge gained by experience. During the last few years an attempt has been made in Europe to reduce the subject of rolling mill practise to some scientific basis but without very great success up to the present time.

It is not the object of this paper to attempt to give any set of rules for determining the correct size and characteristics of the motor required for driving any particular mill but rather to indicate the lines along which such problems must be studied and to give an idea of the factors controlling the size and equipment required. To cover the conditions met in modern steel mills would require a great deal more space than can be allowed in a paper before this Institute and even with full knowledge of such conditions, considerable judgment is always required in working out such problems.

One of the most difficult features of this problem is to determine the set of conditions on which to design the equipment. for any particular mill, that will coincide with the actual practise. It is almost impossible to obtain accurate data from the men responsible for the operation of such installations as to operating conditions, on account of the changes that occur in practise after the mill has been installed, and for this reason any assumptions made when determining the size of machine required for driving it, may be altogether wrong in two or three years. A great many superintendents are of the opinion that it is impossible to obtain, within limits, an equipment too large. This is a mistaken idea but has been based upon past experience which has shown that by improvements, mainly in organization, it has been impossible to increase the output often as much as 100 to 200 per cent over the original estimate. With our present knowledge of rolling conditions and in view of what has been done in the past it should be possible to make a reasonable estimate as to how much the production of a mill may be increased in the future, by improvements in the auxiliary apparatus and organization, and this is a factor which must always be considered when designing an installation; and it is here that the electrical manufacturer must often take the responsibility for assumptions as to rolling conditions altogether different to those given by the steel mill engineers. Some of our most successful manufacturers of rolling mill engines, have based their machines upon the size required to break some part of the mill so that they are certain that the engine would carry any load that could be caused by the mill, independently of the method of operation. So long as efficiency is not considered and it is not necessary to meet competition as to price of the installation, such an arrangement is an ideal one from the standpoint of the manufacturer, as there is never any doubt as to the operation of his part of the plant, but under the conditions now existing in our steel mills, attention must be paid to the question of efficiency, and business conditions also necessitate attention being paid to the price of equipment.

In the first place it must be pointed out that the size of the mill as determined by the size of pinions, or the width and diameter of rolls, has comparatively little to do with the size of motor required for driving it, as the work performed by the same size mill may vary several hundred per cent. The fundamental basis on which the size of motor must be determined, is the product of the mill and the tonnage rolled. There are a great many

factors entering into the proposition which must be considered, and dealing first with the product, the following are the principal in their usual order of importance:

1. Volume of metal displaced.
2. Method of displacement.
3. Temperature of metal.
4. Class of material.
5. Rate of displacement.
6. Size of roll.

This order is not fixed, and the importance of any of the factors will vary with the practise at the particular mill in question.

Volume of Metal Displaced

It is of the greatest importance to have some method of comparing the actual work done on the metal in various mills and it must be admitted that such a comparison is extremely difficult. In comparing various tests, I have used as a unit of work, the h.p.-seconds required to displace one cubic inch of metal. The displaced volume is obtained as shown in Fig. 1. The area enclosed by the full lines, represents the original length of material with the original area A and length L.

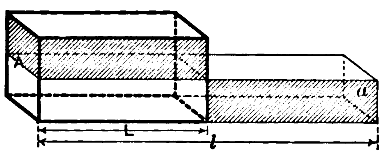


Fig. 1.—Diagram of Displaced Volume

After rolling, the area has been reduced to a and the length increased to l. The shaded portion of the original section, it has been assumed, has been displaced so as to correspond with the shaded part of the metal after the pass. The displacement in practice is of course not as shown but the illustration will show what is meant by displaced volume. From this sketch it is obvious that the volume displaced is equal to $(A - a)\ L$. If the inch is taken as a unit, this formula gives the cubic inches displaced.

This unit of work takes into consideration only the volume displaced in the direction of rolling and for simple work such as rolling plates, blooms, flats, etc., practically all of the metal is displaced in this way as the displacement at right angles to the direction of rolling is negligible. In cases where the section of the pass is completely enclosed by the rolls, there is very often a side displacement which this unit does not take into consideration nor is it my opinion that any simple unit of work can provide for

this condition, as it is impossible to determine exactly how the metal flows. Fig. 2 shows a typical pass when rolling rounds from square billets. The full line shows the section after the pass, and the dotted line the section before the pass. These sections were obtained by cutting pieces from the bar before and after the pass. It will be seen that the width of the material has been appreciably increased, much more than would be natural if the pressure of the rolls were only perpendicular to the bars of the metal.

Attempts have been made to introduce a factor into the comparisons that would take this condition into consideration, it being considered that the metal covered by the area not shaded has not been displaced, but investigations have not yet reached the stage that would warrant any statement being made as to this method of comparing different passes. The instance given in Fig. 2 is a comparatively simple one, but in practise when rolling various sections such as angles, channels, rails, etc., this side displacement is often made under conditions that make it impossible to use anything else but empirical figures. Referring to Fig. 5 showing the sections after the various passes when rolling rails from billets, it will be seen in the case of pass one of the first series, that the metal has been displaced considerably to form the basis of the flange. In this case there has been a considerable distortion of the metal in addition to the increase in the length due to displacement in the direction of rolling and it is obvious that no formula can take into consideration such distortion even if an accurate knowledge were available as to the way that the metal flows. We have some information available as to how metal flows when rolling simple sections such as plates or blooms, but, even with this knowledge, theoretical calculations do not check up very well with practical test results. Various other units of work in addition to the power required to displace a cubic inch of metal, have been adopted by different investigators, but they all take into consideration only the displacement in the direction of rolling, and from what has been said, it is obvious that this is the only basis on which any comparison can be made although it is admittedly open to objection and must be used in conjunction with empirical constants to provide for the distortion of the metal in other directions. I have adopted the unit of h.p.-seconds per cubic inch displaced as it appears to be the most simple and direct basis of comparison. For convenience it will be referred to as "specific power consumption," or S.P.C.

Method of Displacement

Reference has been made to the side flow of the metal, but it is also of the greatest importance to consider how the pressure is applied to the material rolled. When the pressure is vertical, or nearly so, to the surface being rolled, it may be referred to as "direct pressure" and it is obvious under such conditions that the power required, will be a minimum. When finishing material such as flanged rail or channel, where the pressure is almost parallel to the surface being rolled, it is obvious that the actual displacement for a given pressure, may be very small. Such a condition is illustrated in Fig. 3 which shows the condition existing when finishing a rail flange and a channel section. Under such conditions, it is obvious that the component at right angles

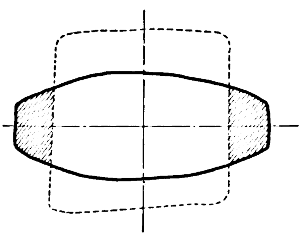


Fig. 2—Pass Sections Rolling rounds from Billets

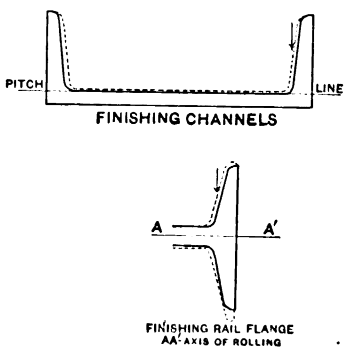


Fig. 3—Examples of Indirect Pressure

to the surface of the metal is very small, and consequently the pressure may be very large for a very small amount of work done. This condition may be referred to as "indirect pressure."

In Fig. 4 is shown a number of sections illustrating what is meant by "direct" and "indirect pressure," and which will make this point clear.

Referring to Fig. 5, a comparison is made of the various passes when rolling rails, and this figure illustrates the difference in practice met with in steel mill work. The second series of sections shows that the rolls are designed to have as direct pressure as possible, whereas in the first set of sections, a great deal of the work is done by indirect pressure. The first series of sections, however, have been laid out so that the axis of the rail during

the finishing passes, is not parallel to that of the rolls and in this way the surface of the metal is worked at a more favorable angle than in case of finishing passes of the second set of sections. It would be reasonable to expect for such conditions that the second set of sections would require less power during the initial passes, but that the finishing passes would require somewhat greater power. This shows to some extent the local problem encountered in steel mills. In Fig. 6 is shown two methods of rolling channels, and it will be seen that in rolling the second set that the direct pressure is used as much as possible and it is only in the last pass that the actual channel section forms. In this pass the volume displaced is negligible, so that the mill has

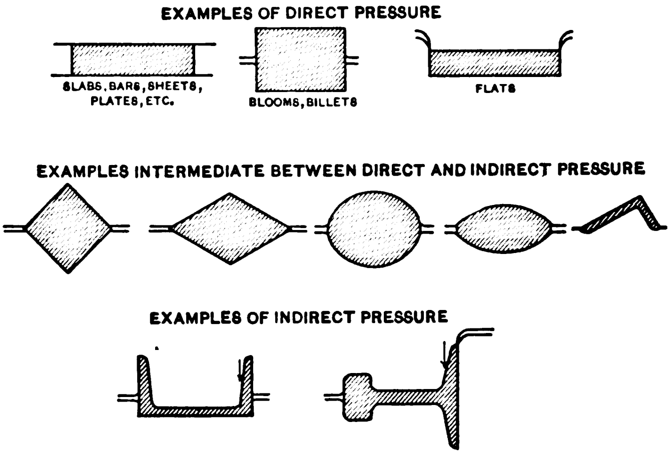
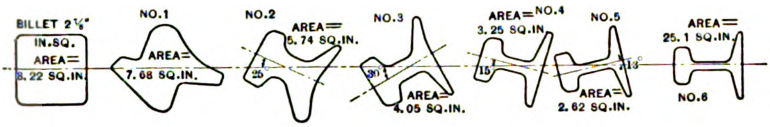


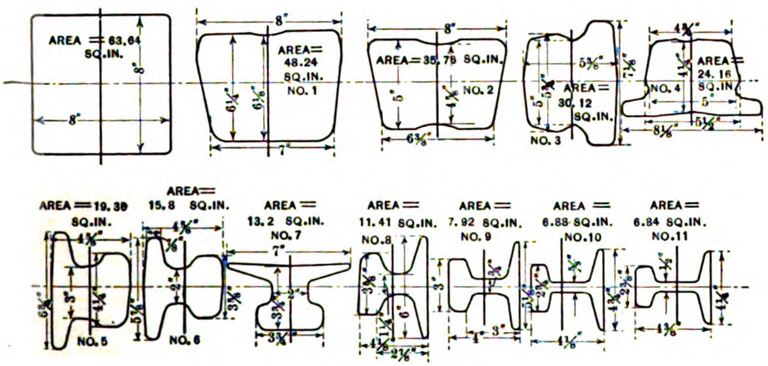
FIG. 4

only to straighten the sides of the channel which has already been formed by direct pressure or pressure at favorable angles. These two examples show the difference in practise in various mills and illustrate to some extent the necessity of studying the particular conditions in each mill before attempting to design an equipment for driving the rolls. The question of roll turning has been based in the past, more or less, upon empirical knowledge obtained by the roll turners from actual experience, but in Europe, some attempt has been made during the last few years to systematize the methods of reducing the metal for different sections, and when this is done the problem of comparing the results to be expected from various mills will be considerably simplified.

The pressure on the rolls due to the metal introduces additional friction but as this cannot be separated from the power actually required to displace the metal, it must be included in the specific power consumption. There is often considerable friction between the rolls and the metal due to the peripheral speeds of various parts of the section being different. On referring to Fig. 5 it is obvious that the speed of the portion of the roll in contact with the web is appreciably greater than that at the edge of the flange and therefore as the flange and the web are delivered at the same rate, there must be slippage somewhere



First Series—Pass Sections Rolling Rails



Second Series—Pass Sections Rolling Rails

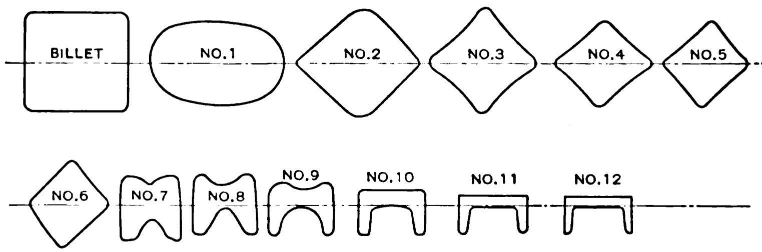
Fig. 5

between the metal and the roll. In cases where a rail flange for instance is being finished, there is a tendency to move the rolls laterally in relation to one another which may be taken up by indirect pressure in the opposite direction or in roll collars, in which case the friction is of course increased. As we have no way of determining what the friction due to rolling may be, it must be included as part of the net rolling work, which is the actual input to the mill less the no-load friction. In the author's opinion, it is perfectly legitimate to consider the additional friction in the rolls, pinions and spindles as part of the net rolling

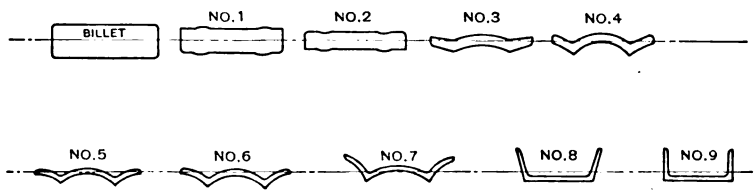
work and I do not think we would be any better off if we had tests showing exactly how much power each item represented, as the problem is so complicated that I doubt if we would be able to make more accurate estimates than are now possible, although perhaps it might be possible to get along with a smaller number of tests.

Temperature of Metal

The temperature of the metal plays a very important part in the power required for any mill. Tests made indicate that the power requirements, all other things being equal, vary practically as tensile strength of the material. There is not a great deal



Pass Section Rolling Channels—First Series



Pass Section Rolling Channels—Second Series

Fig. 6

of information available as to the tensile strength of steel at various temperatures and naturally such tests are rather difficult to make. In Fig. 7 is shown a curve of tensile strength of mild steel at various temperatures, this curve being made up from information that has been published of tests in the Watertown Arsenal and from various European publications, as well as from tests made by the writer. The curve varies somewhat from others that have been published as to the strength at high temperatures, as the tests made by the writer indicate that previous estimates as to the tensile strength have been too low and that instead of the curve gradually tapering to zero at the melting

point, that there is a point somewhere between 1300 and 1400 deg. fahr. where the tensile strength rapidly decreases. Tests made at various temperatures when rolling plates, using only direct pressure, so that there are no other disturbing factors, indicate that this curve is approximately correct as indicating the relation between the power required to displace the metal and the temperature. It will be seen from this curve that the strength increases quite rapidly after the temperature drops below about 1400 deg. fahr. so that when rolling thin sheets,

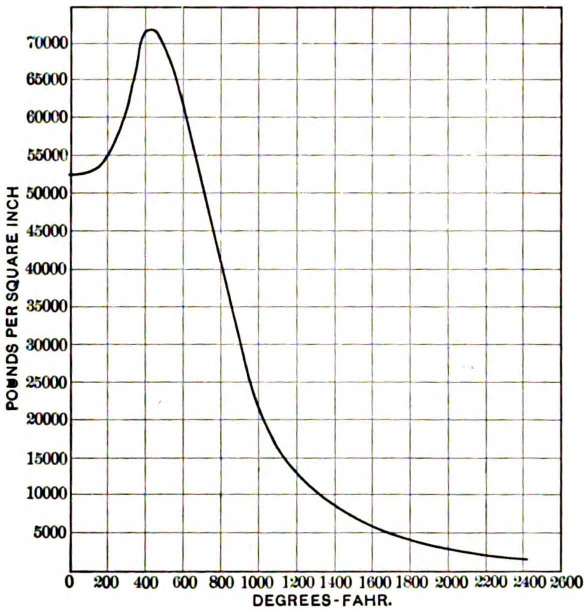


FIG. 7

when the metal becomes almost black the power requirements increase at a very rapid rate. This curve shows that tensile strength about 100 deg. fahr. is about 18 times greater than at 2000 deg. fahr. Tests made when rolling sheets at 2000 deg. fahr. and rolling cold, showed a variation in the power consumption per cubic inch displaced varying from 17:1 to 20:1.

The rate at which metal cools is obviously of the greatest importance and within the usual limits of rolling temperatures it may be said that the rate of cooling will be practically proportional to the area exposed in relation to the volume. In

Fig. 8 is shown the increase in exposed area of a particular slab as the cross sectional area was reduced; and when the rate of cooling is taken into consideration, in conjunction with the curve shown in Fig. 7, it is obvious that the power required to displace the metal will increase very rapidly as the cross section is decreased. This will be referred to later when discussing this point.

Class of Material

Tests made by the writer and by others indicate that, providing the temperature is the same, the power required to displace a given volume of metal, is practically independent of the chemical composition of the steel. This of course applies only when rolling metal hot and within the usual rolling temperatures.

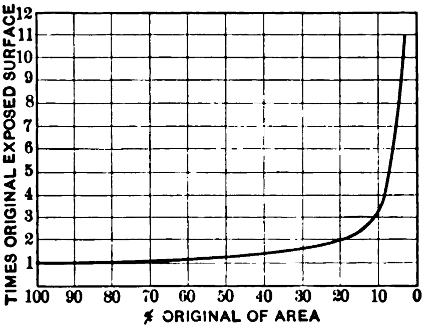


Fig. 8—Showing Increase in Exposed Area of Plate with Reduction in Brass Section

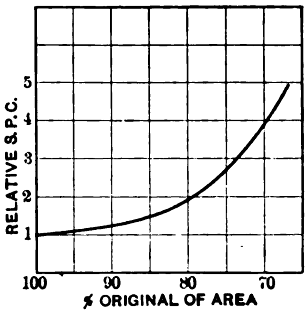


Fig. 9—Showing Increase in Relative Specific Power Consumption—Cold Rolling Steel Plates

As the temperature approaches 1500 deg. fahr. the influence of the different chemical compositions can be noticed, but as metal is usually worked, except in the case of thin sheets or small sections, between 1800 and 2400 deg. fahr., it may be said that in practise, the composition of the material does not directly influence the power consumption. Indirectly however, it has considerable influence, as it is necessary to roll high carbon steels and some alloy steels at comparatively low temperatures, so that the power consumption for a given volume of displacement, may be considerably higher than would be the case when rolling mild steel.

The density of the steel also has considerable influence upon the power requirements, and when rolling ingots, the first one

or two passes made require comparatively little power per cubic inch displaced, as the steel is more or less porous. After the metal has had one or two passes through the rolls, the density when hot apparently does not enter further into the question. When rolling steel cold, there is a continual increase of the power required due to the increased density, and in Fig. 9 is shown a typical curve indicating the increase in power requirements as the cross section area is decreased.

Rate of Displacement

Although little information is available, there are indications that the rate of displacement somewhat affects the power requirements. Tests made by the writer appear to show that a low rate of displacement requires less power than if metal is rolled quickly. In practise, however, metal is rolled as quickly as it can be handled, so that this feature is of comparatively little importance.

Size of Rolls

Theoretical investigations show that when rolling plates or blooms or such sections where direct pressure only is used, the size of roll has some effect upon power requirements. Small rolls should require somewhat less power than large rolls but the writer has not been able to demonstrate the accuracy of these theoretical calculations owing to the great many other factors which influence the test results.

Practical Determination of Motor Size

The great majority of rolling mills are of the type running continuously in one direction, and to equalize the input to the motor, flywheels are used. It is of the greatest importance to determine the size of flywheel required in conjunction with the characteristics of the motor and control apparatus, as it is only by considering them as a unit that a satisfactory installation can be made. It is seldom that a mill is run at such a rate that it is discharging metal from the finishing pass for anything approaching 100 per cent of the running time. Depending upon the class of mill and the work performed, it is usual to find the mill actually rolling from 20 to 80 per cent of the total time. In the heavier mills, the percentage is naturally less than in the case of the mills rolling small sections, and it is therefore obvious that if the motor size is determined upon the basis of rolling so much material per hour, it may be altogether too small to perform

the work while the metal is actually in the rolls, although it might be large enough to take care of the average conditions. With the ideal flywheel, a motor sufficiently large to carry the average load would be the right size to use, as all the peaks would be taken by the flywheel, and during the intervals between passes, energy would be stored in it. In practise it is not possible to use such flywheels, as they would be excessively large, and consequently a compromise must be made between motor and flywheel. It is usual to consider that the mill will run for short periods at its maximum capacity, that is, with the minimum interval necessary to handle the material, and on this basis the load diagram must be determined. The load diagram can be determined from curves showing the power requirements per cubic inch displaced, in conjunction with the volumes displaced and the rate of rolling. From this diagram, the average load, when the mill is rolling at the maximum rate, can be determined, and also the size of the flywheel. The average production of the mill must be taken into consideration in determining the size of motor so as to have an equipment which has suitable characteristics for the normal operating conditions. The curve showing the power required per cubic inch displacement, shows a rapid increase as the cross section area of the material rolled decreases. It is necessary to determine this curve from test data for practically every installation, as local conditions vary so greatly that it is not possible to take any set of curves as representing universal conditions. To illustrate the methods used in determining the size of motor, a load diagram when rolling plates is worked up in detail in Table I which it is believed will show how this problem is handled when the proper data is available. It is of course obvious that this diagram is subject to appreciable variations in practise due to the variation in the condition of the material, temperature etc., but as the curve for power consumption is based upon an average of a number of tests, the diagram is sufficiently accurate to enable the size of the motor and flywheel to be determined. The motor slip under actual operating conditions may be somewhat different from that calculated, but the flywheel will take care of these operating variations. From the load diagram, after allowing for friction, the average load on the motor during the period when the mill is rolling at its maximum rate, can be determined. For perfect operating conditions the flywheel should take all loads in excess of this average load. In practise this is not

TABLE I

Calculation of power required for rolling ¾-in. by 24-in. plate from 4 by 24 by 97.5-in. slab. Rolls 30 in. diameter. Average speed 90 rev. per min. Friction load of mill, 250 h.p. Interval between passes, 5 seconds. Interval between slabs, 20 seconds

Pass No.	Thickness after pass (inches)	Area: Before pass A (sq. inches)	Area: After pass A (sq. inches)	Length: Before pass L (inches)	Length: After pass l (inches)	Time of pass (sec.)	Vol. displaced $(A-a)\ L$ (cu. inches)	Percentage original area before pass	Specific power consumption-h.p.-sec. per cu. in. (Fig. 10)
1	3 9/16	96	85.5	97.5	109.7	0.78	1002	100	1.43
2	2 15/16	85.5	70.5	109.7	133.0	0.94	1643	89	1.57
3	2 7/16	70.5	58.5	133.0	160.0	1.13	1595	73.4	1.80
4	1 15/16	58.5	46.5	160.0	201.5	1.43	1920	60.9	2.05
5	1 7/16	46.5	34.5	201.5	271.5	1.92	2420	48.4	2.38
6	1 1/16	34.5	22.5	271.5	368.0	2.6	2440	35.9	2.83
7	15/16	25.5	22.5	368.0	416.0	2.94	1100	26 6	3.36
8	13/16	22.5	19.5	416.0	480.0	3.4	1250	23.4	3.65
9	12/16	19.5	18.0	480.0	520.0	3.68	720	20.3	4.00

Pass No.	Net rolling work during pass (h.p. sec.)	Total h.p.-sec. during pass, including friction	Horse power-seconds during interval	Output of fly-wheel excess peak above average h.p.-sec.	Returned to flywheel between passes (h.p.-sec.)	Net loss of flywheel energy during pass (h.p.-sec.)	Summation of energy from flywheel (h.p.-sec.)	Maximum output of flywheel after pass (h.p.-sec.)
1	1435	1630	1250	1092				
2	2580	2815	1250	2167				
3	2870	3152	1250	2374	2197	177	177	2374
4	3940	4298	1250	3313	2197	1116	1293	3490
5	5760	6240	1250	4917	2197	2720	4013	6210
6	6900	7550	1250	5758	2197	3561	7574	9771
7	3700	4435	1250	2410	2197	213	7787	9984
8	4560	5410	1250	3070	2197	873	8660	10857
9	2880	3800	5000	1263	8788	+ 7525	1135	9923

always feasible, but it must be remembered that the type of control also has considerable influence upon the input to the motor. If the speed of the motor is to be regulated in such a way that the motor takes only the average load, it is necessary to automatically vary the resistance of the rotor circuit. The usual method of control in rolling mills, is to use a fixed rotor resistance, so that the speed falls as the load is increased. This gives a more or less satisfactory control of the flywheel, but in the majority of cases it leaves a great deal to be desired. Efficient control devices have been designed which will automatically regulate the rotor resistance quickly enough to meet rolling mill

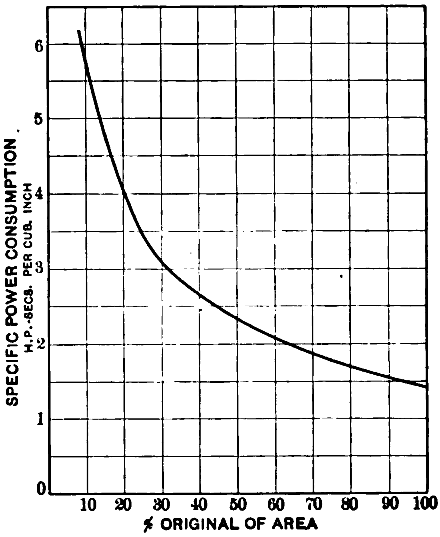


FIG. 10

conditions, and a description of one successful type has been already given by the author.* In the table calculated, it has been assumed that automatic slip regulation is provided for, so that the flywheel will take all loads in excess of the average, and from the load diagram, the capacity of the flywheel can be readily determined. In Fig. 10 is shown the curve from which the S. P. C. has been obtained. This curve represents the average of a number of tests. In Fig. 11 is shown the load diagram corresponding to the table, which shows the work to be performed by the motor and flywheel. In practice it has been found that, al-

*PROCEEDINGS A. I. E. E., June 1911.

though the power required for the individual passes may vary quite appreciably from that calculated, the flywheel will have sufficient capacity to compensate for these individual variations, and that the general operating conditions of the motor can be fairly accurately determined. It has been pointed out that the daily or hourly capacity of a mill may be very much less than the maximum possible capacity, and it is necessary to compromise between the size of machine required to handle the maximum possible output and the actual hourly and daily output. For instance, in the example that has been worked out, the average load on the motor is 675 h.p. when the mill is run at its maximum rate of production. The actual hourly rate of production of this mill is only 80 per cent of this maximum, so

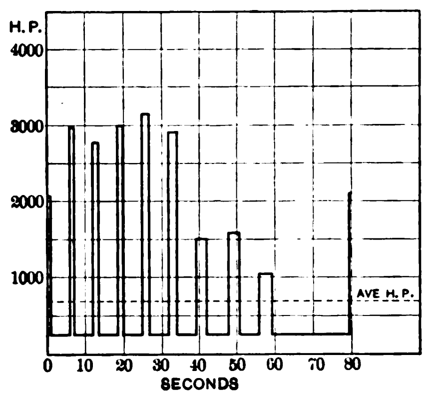


FIG. 11—LOAD DIAGRAM CORRESPONDING TO TABLE I

that if the normal rating of the motor is such that it would carry the hourly average, it would be overloaded 25 per cent when working at the maximum rate of production.

In practice it is advisable not to allow for an overload of more than 25 per cent when rolling at the maximum possible rate, so that there is always a certain reserve available in the motor for extraordinary conditions that may arise. Rolling mill motors are usually designed so that they can carry 25 per cent overload continuously with a 50 deg. cent. rise and 50 per cent for one hour with a 60 deg. cent. rise. With motors designed on this basis, it is quite permissible to allow for them being overloaded 25 per cent when the mill is run at its maximum capacity. If the hourly capacity of the mill is considerably less than the

maximum that can be rolled, it is then necessary to investigate very closely the conditions existing so as to determine on what basis the compromise must be made.

In the foregoing, attention has been drawn to some of the features controlling the power requirements of rolling mills and it is hoped that at some future date that it will be possible to discuss this problem more in detail when a fuller knowledge is available of the various constants that must be considered when dealing with this proposition. The examples given represent simple conditions and it will be readily appreciated that the great variety of shapes rolled makes the actual determination of power requirements very difficult. Curves showing the specific power consumption are not as a rule so regular as for plates, which represent the simplest condition met with and the one not interferred with by such items as indirect pressure, collar friction, etc.

DISCUSSION ON "DIRECT-CURRENT AND ALTERNATING-CURRENT MILL MOTORS FOR AUXILIARY DRIVES" (WILEY), PITTSBURGH, PA. APRIL 25, 1912. (SEE PROCEEDINGS FOR MAY, 1912).

(Subject to final revision for the Transactions.)

Alexander C. Lanier: Mr. Wiley's paper has brought out the principal demands made upon motors in mill and crane service and my remarks will be limited to direct-current motors suitable for such applications. Commutation is always a factor of first importance in the direct-current motor; service conditions met in mill work are much more severe than in the ordinary industrial application. During the operating cycle the load usually varies between wide limits, and momentary peaks may reach three or four times the one hour rated load.

The commutating pole motor is particularly suitable for such conditions. I shall only mention in passing the long recognized principle underlying commutating pole design. By providing at the point of commutation, a flux closely proportional over a wide load range to the current commutated, its value in general such as to give straight line reversal of current under the brush and its magnetizing current in series and therefore, in time phase, with the armature current, the commutating range of the machine is greatly extended. For motors in reversing service, with neutral setting of brushes, commutation is better provided for, in properly designed commutating pole machine, under heavy overload conditions than in the normal non-commutating pole type at rated load. In the design of commutating pole motors of strongly drooping characteristics, slight over compensation at normal load will add somewhat to the overload range of the motor. The short circuit voltage per brush and per coil should also be kept within proper limits.

In commenting upon the root-mean-square method for selecting motors for a given service, with known operating cycle, and length of time during which the cycle is repeated continuously, attention is directed particularly to the utility of a table of ratings covering a wide range of time period as indicated in Mr. Wiley's paper. Beside the application in which there is practically continuous repetition of the cycle over five hour periods, frequent cases arise in which the motor is subjected to very heavy loads of short duration, followed by long periods of light load or absolute rest. Since the temperature rise of a motor under loads of short duration is a function of the heat capacity of the machine more largely than its radiating properties, the short time rating of the motor in such cases forms a ready basis for its selection.

M. A. Whiting: There is one point concerning which I should like to have Mr. Wiley go into a little further detail, *i. e.*, he states that the heating effect of a varying load is best expressed in terms of an equivalent continuous load with the voltage at the motor terminals reduced. I should be interested to know how great a reduction in voltage Mr. Wiley has in mind

and just what conditions such a rating at reduced voltage is intended to cover. For example, it could be made to cover merely the operation of the motor during accelerating periods, during which the voltage impressed on the motor armature varies from zero to full line voltage, or it could take account of the probability of prevailing condition of low average plant voltage. Further information on this point would therefore be of interest.

The root-mean-square method, which Mr. Wiley explains and illustrates, is of course by far the best known and most widely used method for estimating the heating of a motor on a varying load, but in some cases this method introduces serious discrepancies. It is therefore, of interest to consider under what conditions the discrepancies occur and in which direction they affect the result. This is not a criticism of the use of the root-mean-square method in general, but merely a consideration of its application with reference to certain cases. The accuracy of this method depends on the shape of the efficiency curve of the motor over the range of loads considered. Take for example, the curve in Fig. 7. covering a series motor with a nominal rating of 30 h.p. As the heating curve is not given, we may assume, for the purpose of discussion that the continuous capacity of the motor is one-half the full load current. In using the r.m.s. method for a continuous cycle (*i.e.* for a cycle repeated continuously for, say, twenty-four hours) after determining the r.m.s. equivalent of the load we compare it with the continuous capacity of the motor for the allowable temperature rise. In doing this the assumption is made that the total *kw. losses* of the motor vary as the square of the load, or, expressed in other terms, the assumption is made that the *per cent losses* vary directly as the load. The efficiency curve assumed by the r.m.s. method therefore begins at the point of 100 per cent efficiency —zero load, and consists of a straight line extending down at an angle and intersecting the actual efficiency curve at the point corresponding to the continuous capacity of the motor, (in the present case, Fig. 7 of Mr. Wiley's paper, assumed at half load as stated above). Where the actual efficiency curve follows very closely this straight line, the r.m.s. method will be very close. But in the figure under consideration the actual efficiency curve crosses this straight-line efficiency curve at a considerable angle, so that the actual losses at heavy loads are less, and at very light loads are greater than indicated by this hypothetical straight-line efficiency curve laid out in accordance with the r.m.s. assumption.

I have had occasion to work out a number of cases along this line (not however in connection with this paper), which show the following:

First, if the loads in a cycle are at all times below the basic value with which the comparison is made (*i.e.* are at all times below the continuous capacity of the motor) the heating will

be greater than indicated by the r.m.s. method (although, of course, still below the capacity of the motor).

Second, if the loads are all above this basic value, interspersed with periods of rest and periods during which the motor coasts without load, the heating will be less than indicated by the r.m.s. method.

Third, if the loads are partly above and partly below the basic value the losses may be greater or less than indicated by the r.m.s. method. Where the loads vary above and below the basic value in this manner the errors, due to the r.m.s. method showing too low losses at light loads and too high losses at heavy loads, tend to compensate, so that on this kind of cycle the discrepancy will usually be much smaller than in cases 1 and 2.

Referring to the induction motor curve, Fig. 7, we note that the efficiency curve is more nearly level at overloads than is the case for the direct-current motors, Figs. 7 and 8, *i.e.* the losses for this induction motor deviate more greatly from the r.m.s. assumption, and the method is more inaccurate. In general a motor with high iron losses and low armature and series field copper losses will vary more from the r.m.s. assumption than will a motor with large armature and series field losses and small iron losses.

To compare the relative accuracy of the r.m.s. method for open and enclosed motors we may refer to Fig. 7, and consider this efficiency curve as applying to an open motor having a continuous rating of 30 h.p. In this case the basic value assumed in using the r.m.s. method will be, as before, the continuous capacity of the motor (in this case 30 h.p.).. If we draw a straight line efficiency curve on this figure, in the same manner as previously but intersecting the actual efficiency curve at 30 h.p. these two curves lie close together over a considerable distance, and the r.m.s. method will therefore be much closer than in the case of the enclosed motor discussed above.

In practically every open motor of normal design the losses at the continuous rating of the motor are principally load copper losses, whereas with any enclosed motor, on account of the reduction in continuous output, the iron losses form a large percentage of the total losses at the continuous rating of the motor. It will in almost all cases be true, therefore, that the root-mean-square method is liable to greater inaccuracies when applied to an enclosed motor than when applied to an open motor.

R. B. Treat: There is a class of service to which the commutating pole mill motor is not well adapted. We had an illustration on the screen of a screw down motor and a front and back catcher table motor. This is the type of service referred to, requiring momentary high torque for very short times. The normal commutating pole mill motor will easily stand 50 per cent over its rated load. At 100 per cent overload that motor will commence to spark. At 200 per cent overload the sparking

of the brushes is worse than if there were no commutating poles present. Screw down and catcher table service requires commutating capacity rather than heat capacity in the motor. The commutating poles should therefore be designed for the 200 or 300 per cent overload current, but such a design is not found in commutating pole mill motors of a size necessary for screw down or catcher tables.

It may be true that small commutating pole mill motors (25 h.p. more or less) have been run satisfactorily in the factory with three, four or five times rated load. The design which permits this in a 25 h.p. size does not prevail in a 75 or 100 h.p. size. There is no comparison between a small motor on factory test and a large motor on screw down or table service.

There is another feature, too. The peak current is instantaneous, mounts to its maximum value, and then drops off within a small fraction of a second. The flux set up by the windings on the commutating pole comes along a little later,—after the current has subsided. It is not in synchronism with the load current. The load current is present without any commutating flux, there is sparking. The load current subsides, the commutating flux comes, and again there is sparking. For each rapid current change of great magnitude there are two sparking intervals in a commutating pole motor and only one in a non-commutating pole machine.

One sentence in the paper reads " and the recently developed type of controllers provides special protection against unnecessarily severe conditions being imposed on the motors." These controllers protect both commutating pole and non-commutating pole motors against unnecessarily severe conditions. If the controller does it, why not omit the commutating pole entirely, and have a somewhat simpler machine? The author states that the torque of an a-c. mill motor is greatly dependent upon proper adjustment of resistances while the torque of a d-c. motor is more independent of resistance adjustment. He then goes on to state " these inherent features " of the a-c. mill motors protect the driven machines and the driving motor. It would seem more appropriate to state that " these inherent features " of the a-c. mill motors are so troublesome as to recommend the abandonment of the a-c. mill motor, a conclusion which at least one steel mill has almost arrived at.

Gano Dunn: The standardization rules, and, in fact, the standardization methods in all countries, are in need of a definition of what the relation of the root-mean-square to the real capacity of an intermittently used motor is.

The methods at present in use for rating intermittent service motors, as Mr. Whiting very properly pointed out, do not take directly into account the heat absorptive capacity of the motor, nor do they take into account many other things, and, as he has said, the accuracy of applying the r.m.s. method really depends upon the shape of the efficiency curve of the particular motor

in question, not to mention the motor's absorptive capacity and several other factors which might be mentioned.

When, in the early history of the standardization rules, the question was up of a simple way of determining, artificially, if you will, the efficiency of generators, the rules incorporated methods which, while not entirely accurate, were so simple that they became universally employed, such, for instance, as measuring the no-load losses and then arriving by calculation at the resistance and other losses, making a result that was partly calculated and partly measured.

Now, just this kind of thing is needed in the case of intermittent service motors. Mr. Whiting's discussion contributes a good deal in that direction. For instance, if we could adopt some standard type of efficiency curve, and assume it to apply to all intermittent service motors, and then make such modifications in the r.m.s. rule as would cause that rule to be applicable to that particular type of efficiency curve, we would have secured an approximation that would undoubtedly be sufficiently close for all purposes, and would enable us to discuss intermittent service motors more intelligently than we now do.

We ought then to add to any ratings arrived at by that method, a factor representing the absorptive capacity of the motor; so that given what you might call the equivalent continuous load of a motor, or given its cycle in intermittent service, and stipulating that the standard or arbitrarily adopted efficiency curve for heating shall apply to calculations in connection with this motor, we would have by applying to these results the absorptive factor, a method by which we could compare a German motor with an American motor, or with motors made in any country, and by which we could compare motors of different manufacture in this country, even if their weight and absorptive capacity, and general characteristics were very different.

If Mr. Wiley's paper and the discussion on it can stimulate the development of a method of arriving at some arbitrary basis of comparison between intermittent service motors better than the r.m.s. method, taking into account the absorptive capacity of the motors for heat, it will have done a great service.

F. R. Fishback: Mr. Wiley has given some tables in his paper, and I get the general impression that he believes alternating current should be used for auxiliary drives. The principle argument in favor of the a-c. motor is the question of line transmission and commutator troubles, the big bugbear of all our troubles. With commutators designed to take care of the present day loads, we can neglect the commutator question. In the table referred to, Mr. Wiley states that during a period of a year, and covering a large number of motors, no new commutators were put on, no new shafts were required and only 10 new sets of armature coils. Six of these were for 25-h.p. motors and four for 50-h.p. motors. The total repairs according to the table, have been purely a question of armature coils. I think it is

also safe to assume that in the list of motors taken, a large per cent of the motors were controlled with the manual controllers. I say this because it has not been common practise until recently to put automatic controllers on motors of 50 h.p. or under. With automatic control on all of the motors in the table above, the number of new armature coils required could have been greatly reduced, if not eliminated.

There is also a question of the electric brake that enters into the question of repairs on a motor. The d-c. brake is a much simpler one than the a-c. brake. A long stroke plunger can be used, and this gives plenty of leeway and clearance in designing the brake. The d-c. brake consists of a steel casting, a winding and a steel plunger. The a-c. brake has a short stroke plunger and is made up of laminated pieces, which chatter and easily get out of order.

The d-c. motor is the only right motor for auxiliary drive. The d-c. motor has the advantage over the a-c. motor of speed control and dynamic braking, and the most important advantage of all in that it will lift above its capacity until it burns out. This characteristic of the d-c. motor is most important in steel mill work where it is often cheaper to burn out an armature rather than wreck a more expensive machine or kill a man.

A. G. Ahrens: In connection with Mr. Treat's criticism of the commutating pole motor, that it is not able to stand heavy overloads of torque, I do not think Mr. Treat had in mind the mill motor. Mr. Lanier pointed out that the mill motor on ordinary loads is under-commutated, so to speak, so that on extreme overloads it is found that it commutates at its best. I have seen mill motors under a test with the special object of obtaining data as to its commutating ability, and I remember one test in which the motor was rated at 25 h.p., mill rating, which is equivalent to an armature current of 113 amperes, and under 400 amperes load, which is equivalent to over 350 per cent of normal load, that motor was sparking slightly, a condition of commutation which would have been called good on any industrial motor.

Brent Wiley: In regard to Mr. Whiting's question concerning reduced voltage, this subject has been considered from the standpoint of average conditions for motors operating with widely and rapidly fluctuating loads. This average condition is assumed to be such that the average voltage during the entire day, where 24-hour service is required, is one-half normal line voltage. For example, if the normal line voltage is 230 volts, the average voltage is figured at 115 volts for a cycle in which the motor is operating at full voltage approximately 40 per cent of the total time; and the heating of the motor is calculated on the basis of the equivalent continuous current at this reduced voltage. Operation with reduced voltage at armature terminals, due to insertion of resistance in series, for a greater percentage of time, would give equivalent results.

For a large majority of the applications for which the mill motor is particularly suitable, it is practically impossible to predetermine the exact cycle of operation, including time and load. It has been determined, however, that by averaging the data and conditions for various installations in steel mills, the actual operating period of the motor is approximately 40 per cent of the total period, and the table of ratings given has been developed on the basis of average voltage at the motor terminals equal to one-half normal line voltage.

It would be of advantage to take the motor characteristics into consideration when calculating the heating effect of a varying load for those cases where the load curve can be predetermined accurately; and further investigation of this point would be of value. It is questionable, however, if the attempt to apply such a close theoretical analysis would be of practical value for the general application of mill type motors.

Mr. Treat has questioned the ability of the commutating pole mill motor to meet successfully the severe conditions of steel mill work.

The particular function of the commutating pole feature is to give better commutation over a wider range of operating conditions than can be obtained by the non-commutating pole motor. With the conditions to be met well established, there are no reasons why the proper commutating pole features cannot be included and better results obtained. It is true that, until a comparatively recent period, the theory of commutating pole design was not well established, and its application to motor design was therefore somewhat limited; but the unqualified success of the commutating pole railway motor is a forceful demonstration that for even severe, intermittent and widely varying load conditions, commutating poles are of great advantage.

Mr. Treat's criticism of the commutating pole motor for use in heavy duty reversing service seems to be based on some particular design. It has come to be recognized that motors must be designed particularly for this service, electrically as well as mechanically. No one conversant with conditions would apply a motor in this service having the same mechanical design as a motor suitable for, say, printing press drive. It is important to have a liberal electrical design and the use of the commutating pole permits this without going to proportions of armature that would make the machine excessively large. It is perfectly practicable to so proportion motors of the largest sizes required in this service that they will commutate the heavy overloads sparklessly, at the same time giving sparkless commutation on full load and lighter loads.

The time lag referred to between the current inrush and the building up of the flux is very much less than might be supposed, since the ampere-turns on the pole are ample to force the flux, not only through the pole, but also through the gap. As the ampere-turns required for the gap are many times those required for the

iron part of the circuit, there is a very high m.m.f. forcing the rapid building up of the flux.

Results actually secured with commutating pole motors in this service show that no injurious results follow due to this very slight time lag.

There are many applications of the commutating pole mill motor being made on the mill machinery referred to by Mr. Treat, and from the preliminary tests that have been made, improved commutating conditions, as compared with those obtained with the older types of non-commutating pole motors, can be assured.

The reference which was made in my paper to improvements in control apparatus has a more significant meaning than has been brought out in the discussion. The point is that these improved conditions make it possible in many cases to increase the working capacity of the motor by the use of commutating poles. The function of series relays and series switches is to limit the accelerating and braking current to a predetermined amount. In the majority of applications, rapid acceleration and retardation are desirable, limited, however, to such values as are necessary to protect machinery and motor. With commutating pole motors these values of the current will be more dependent on the limits imposed by the machinery rather than by the motor. As the commutation limit has been raised, it means that the working capacity of the motor has been raised. It becomes more a question of heating limitations and, as stated previously, fireproof windings permit a much higher safe rise of temperature than can be obtained with the older types of motors.

Regarding the question of the relative merits of the alternating-current and the direct-current mill motors, as mentioned by Mr. Treat and Mr. Fishback, this is a very broad subject and it is not within the scope of this paper to give the various points proper discussion. There is no doubt that, for the most severe service, such as screw drives and reversing tables, the direct-current series motor has more advantageous characteristics. This is equally true of the hoist motion of cranes; but the question whether one type of motor or the other should be used should not be answered on this basis alone. With the increased attention which is being given the question of economies, there is good reason to believe that the application of the alternating-current mill motor will be made in accordance with the saving that it will insure. Much progress has been made regarding the design of an alternating-current mill motor with suitable features for this severe duty, and a careful study of the gradual applications by the designing and the field engineer will insure further progress in the successful application of this type of motor.

DISCUSSION ON "MOTOR AND CONTROL EQUIPMENT OF ELECTRICALLY OPERATED VALVES" (GASSMAN), PITTSBURGH, PA., APRIL 25, 1912. (SEE PROCEEDINGS FOR MAY, 1912).

(Subject to final revision for the Transactions.)

H. A. Knoener: A mechanical motion could be arranged which would help out matters in connection with sticking or jammed seats on large valves. For instance, the valve stem could be so arranged that it would have a lost motion when opening or closing the valve. This would allow the motor to get up to full speed before being called upon do do the work required to release a jam. This is particularly applicable to gate valves.

Walter C. Kennedy: There has been considerable work done in connection with automatic valve control. The motors used for this class of work are usually of small size, in most cases not over five h.p. They are very often provided with a heavy compound winding with enough shunt to prevent undue high speed. Very often a special high resistance series-wound motor is used similar to that employed for compressor work in railway service. This is usually thrown directly across the line in starting and gives a high starting torque.

The matter of acceleration in valve control is of minor importance; the principal result to be accomplished is an accurate stop at either limit of travel. Where motors are thrown directly across the line, overload protection is obtained by short-circuiting the overload coil in starting, and then cutting this back into circuit in the normal running position. This prevents the overload from tripping on the starting surge and allows it to be set for a close value within the rating of the motor. In stopping, this overload movement can be tripped by a shunt tripping coil which is energized by contacts on a suitable limit switch. For ordinary service the limit switch is connected to stop the valve at the extreme limits of travel, but can be easily wired so as to allow a partial opening of the valve. Indicating lamps can be arranged in connection with a hand operated dial indicator to show the position of the valve gate when stopped at any intermediate point of travel.

To facilitate a more accurate stop, it is common practise to use a slow-down feature operated by the limit switch, or else a single step of dynamic braking to take effect after the limit switch has operated to shut off the power. This latter method is used on compound-wound motors only.

Gano Dunn: A year ago I suggested to the sub-committee on Rating of the Standards Committee, of which sub-committee Mr. Robbins is now chairman, that this type of motor be called a "motion" motor. There is a rapidly increasing demand for it, not only for valves, but for closing bulkhead doors and hundreds of purposes one would not at first think of. It presented a new problem in rating, and I think we will be interested to hear from Mr. Robbins, as a contribution to the discussion of the paper now before us, as to what has been done, if anything, towards the rating of the motion motors.

Charles Robbins: The sub-committee on Ratings of the Standards Committee of the Institute gave considerable thought to a proper definition of a motor performing similar service to that required in the operation of screw-downs, valves and elevating cross rails on machine tools. During this discussion Mr. Dunn recommended the term "motion motor," but on further investigation the committee decided that such a term was not thoroughly descriptive; therefore, up to the present time they have not adopted the term "motion motor," although we are frank to sav that no better name has been suggested.

The sub-committee believed that it was necessary to have several classifications of ratings, which for the present they have defined as (a) short time service, (b) continuous service. It is recognized by the committee that there would be different classes of duty under both of the above mentioned services; therefore, the duty has been divided into three general classes: (a) continuous duty, (b) periodic duty, (c) pulsating duty.

Heretofore the term "intermittent service" has been usually submitted to cover that duty which the motor was called on to perform other than for continuous operation, and it was thought that this term "intermittent service" was not sufficiently specific, therefore, the divisions above suggested were tentatively adopted.

The so-called "motion motor" would undoubtedly come in the classification of the short time service, continuous duty; that is to say, a screw-down motor would be used infrequently, but in service would operate continuously at its capacity. The rating on this class of motor might be for one minute, or five minutes or longer according to the conditions under which it is called upon to operate.

The work of the sub-commitee has not progressed sufficiently far enough to enable it to make a definite report to the Standards Committee, and for that reason we would prefer not to enter into too much of an explanation of the preliminary conclusions of the sub-committee, for the reason that additional data and ideas of others may cause certain changes in the suggested ratings. At all events, the committee is thoroughly convinced that the classifications mentioned will cover every class of duty found in steel mill service, and that when motors are so rated, and performance given on the basis selected for ratings, that a more intelligent selection of equipments can be made with a much more definite knowledge of what the apparatus will do under the conditions of service to which it is applied.

H. M. Gassman: As to the mechanical device referred to by Mr. Knoener, I have referred to that matter in the paper. I understand there are other devices of an equivalent nature, depending on the construction of the valve. Some large gate valves are constructed with the gate V-shape, and others have parallel sides, with gates that go down to the closing point, and are followed up by a wedge forcing the gates tightly against the side. Each type of valve requires separate treatment.

DISCUSSION ON "ADVANTAGES OF AUTOMATIC CONTROL IN STEEL PLANT OPERATION" (COEY), PITTSBURGH, PA. APRIL 25, 1912. (SEE PROCEEDINGS FOR MAY, 1912).

(Subject to final revision for the Transactions.)

H. C. Specht: From Mr. Coey's paper one might gain the impression that the automatic control should be recommended in every case. I do not believe that this is the intention of the author. Whether an automatic or a manual operated control should be used, depends on various conditions. It is true, that as a rule the automatic control can do more work in the same time than a man by a hand control can do. But very often the fact is overlooked that the automatic control entails some complication, which gives a greater chance for minor trouble, and cannot always be located quickly, and, therefore, causes a good deal of loss in time and money. Certainly the series d-c. switch is a wonderful improvement in automatic control system and will give good service, and it is to be hoped that there will soon be invented an equivalent switch for automatic alternating-current control.

John C. Reed: Great stress has been placed upon interlocking devices used on controllers operating table motors. The trouble experienced in the use of these devices is, that if they work, the motor cannot be operated in case anything out of the ordinary happens, while if they do not work they may as well not be there. Some time ago I started in weeding out these interlocking devices on controllers using series switches for acceleration until I did not have anything left but the mechanical interlock between the reversing switches. In this way I have made the controllers very simple so there is little about them to get out of order. This of course removes the protection the motor would otherwise have in case one of the series switches should fail to open. I take care of this, however, by using a motor of ample size so that it is permissible to leave some resistance always in circuit, just enough to permit the motor being operated across the line with this resistance in series. It would not of course be advisable to operate in this manner for a long time, but the inspector will discover the trouble and reapir the same before any damage results.

The advantages of this system are as follows:

First. It cheapens and simplifies the controller.

Second. It eliminates delays which would otherwise occur due to trouble in the interlocking devices and to sticking of the series switches.

Third. It prevents the loss due to the spoiling of any steel during the process of rolling caused by delays which would otherwise occur.

Fourth. It provides automatic acceleration more than 99 per cent of the time, and the balance of the time the strain on the motor and machinery is no greater than was formerly experienced at all times when manual controllers were used.

R. A. Black: I can endorse what Mr. Reed has said, as well as Mr. Coey, as to the use of magnetic control. I have under my charge a great deal of magnetic control, and it is a question of getting out the steel and getting it out as quickly as possible. Of course it is understood that the men are working on a tonnage basis, and are anxious to get the work out as fast as possible, and if we put on too many precautions as to the care of the motor by the magnetic control, we will lose a good deal of time. The advantage of the magnetic control is that it is so simple—the master controllers are so easily operated that it is possible to turn out the work much more quickly than with manual control, and if you do have occasional delays on account of trouble on the local circuit somewhere that is not easily found, you make up for it in the time you gain by the easy operation of the controller.

So far as heavy overloads are concerned, with the reversing and plugging of the motors in steel mill work, it is almost absolutely useless to try to put on an overload feature. In so doing one has his troubles in delaying the mill. As we heard a short time ago, the mill type motor is developed and built now so that it will stand current 300 per cent in excess of normal rating, and if you do have one or two switches sticking, the motor takes care of this, as it is built for that purpose. Of course the principle of the magnetic control is to care for the motor, but we must not forget the output of the mill.

The new switch which has been brought out by different concerns, has, of course, eliminated a lot of the auxiliary contacts, etc., and makes it much easier for us to locate any trouble, and I believe in a short time they will have these even more simple than they are at the present time.

But another thing in connection with magnetic control is the use of the dynamic brake. If you have mechanical interlocking which locks out the dynamic brake switch, which is ready to go in almost the instant the motor starts, especially on heavy roll table motors, it is impossible to plug the motor until the dynamic brake switch falls out. This of course does not occur until the motor slows down considerably, allowing the current which holds the dynamic brake in, to fall low enough for the switch to fall out. In some mills they claim they cannot do this on account of the rapid reversing of the motor which is necessary to turn out the steel.

T. E. Tynes: One point which Mr. Reed has mentioned indirectly is the variation of the load on the motor. The idea of the automatic board is to protect the motor from excessive overloads. You may get these overloads, not due to carelessness of the operator, but due to operating conditions. On some of the older tables in the mills it is difficult to get out the scale during the operation of the mill; I have seen scale accumulate between the rollers until you get a heavy braking effect, and the result is the relays will hold up and the motor will not accelerate.

If there could be a current limiting device, in connection with a time limiting device, so that after a certain time elapsed the motor would accelerate, it seems to me that would be an ideal condition in many applications of the steel mill motor.

On some of our equipments where the reversing service is fast, we put in one additional contactor and put in sufficient resistance on that to take care of the plug. At the instant of the reversal the counter e.m.f. is added to the line voltage and you get an excessive current. We put in one additional contactor to take care of that condition. Starting from rest the extra contactor will close rapidly, but on a plug the contactor will hold out longer, or until the current falls to what it would be, starting from rest.

W. F. Detwiler: I should like to know from the author of the paper, or some of the other gentlemen, if they have experienced any trouble, on flywheel commutating, of the voltage switch, or main accelerating switch, holding in from back or counter e.m.f., and what remedy they have adopted to overcome that trouble.

Stewart C. Coey: If the last accelerating switch has a shunt "holding-in" coil it is necessary to make your operating switch break the circuit of your shunt "holding-in" coil or else your coil will hold in until the voltage generated by the motor drops to about 60 per cent of the line voltage. This effect is especially noticeable in the case of a shunt-wound motor, the load on which offers a large flywheel effect. In this case, unless there is a means provided for breaking the circuit of the shunt "holding-in" coil, the speed of the motor may drop very considerably before this last switch falls out, and if the motor is thrown on just before this falls out there will be an excessive rush of current and at times flashing over on the commutator.

W. F. Detwiler: Suppose it is a series contactor, and your back e.m.f. will come back to zero, and not return at that rate, you do not have that much current to bring back in again.

S. C. Coey: If it is a series holding coil, as soon as you break your line circuit your contactor drops out.

W. F. Detwiler: I do not mean to break the line circuit—the line circuit is still complete—you get your commutating because the back e.m.f. drops the contact rapidly.

S. C. Coey: In that case the motor runs on resistance until the load comes on and pulls down the speed, which will in turn cause the current input to increase and the contactors will come in in their regular order.

W. F. Detwiler: It is that which we are trying to effect.

Mr. Linn: Mr. Coey's paper states that "on account of the speed necessary in operation, dynamic braking cannot be used for stopping the motor with success." That is in connection with screw-down motors. I believe, with the construction of the double-throw contactor so that as the contactor drops open, it makes the braking action on the reverse switch with greater

speed and most satisfactory service that can be secured, both from output standpoint and from the standpoint of accuracy for the operator. If, in addition to the straight double-throw contactor, a series winding be placed to hold the contactor in the braking position, then you have a positive assurance that no injurious peaks will occur, should the operator pass from full speed in one direction to full speed in a reverse direction, because as soon as the braking contact is made the current from the series winding will hold the braking contact in position until the motor has come to rest, and then the current will instantly be applied in the reverse direction. The saving in time occurs in cutting out the lag which is always present in operating shunt-wound magnets with a double-throw contactor. That lag is entirely eliminated, except the lag present in de-energizing the shunt winding. I believe that will give a more satisfactory control from the standpoint of current consumption and accuracy in operation.

Stewart C. Coey: In regard to Mr. Specht's point that if you can get good operators it would do away with automatic control, I think we have as good operators as you can find anywhere in the country; and about two weeks ago I put in an ammeter on some mill motors running tables, with manual controllers, without the men knowing it, and the running load was from 70 to 100 amperes on both tables and the peak load on plugging and reversing ran from 600 to 900 amperes, and sometimes above 1000 amperes, which was the limit of the ammeter. These men were apparently using these controllers as well as any ordinary men could operate manual controllers.

As to Mr. Linn's point on dynamic braking, I understand that what he has in mind is something like the planer controller that gives dynamic braking without closing another shunt switch, and I think possibly that this scheme might work out, although closing another shunt switch has been found to be too slow to work in this particular case.

Mr. Specht and Mr. Reed brought up the point that simplicity is really the essential factor in automatic control, and it is only due to the fact that the series switch has made simplicity possible that it is at all possible to apply this automatic control to the smaller sizes of motors.

DISCUSSION ON "ELECTRIFICATION OF A REVERSING MILL OF THE ALGOMA STEEL COMPANY" (MCCORMICK), PITTSBURGH, PA., APRIL 26, 1912. (SEE PROCEEDINGS FOR APRIL, 1912).

(Subject to final revision for the Transactions.)

David Hall: The importance of apparatus of this kind and the safety of operation so that there will be no breakdown are of such magnitude that each point has to be very carefully considered in the design, and there are a number of points, regarding which I desire to ask some questions.

The successful operation of machines of such importance as these and of such magnitude is certainly a great credit to the engineers who are interested. I am to understand that the line circuit is grounded at the central point. The paper does not mention that, but I understand that is the condition of operation. I would like to be assured on that point.

B. T. McCormick: That is correct.

David Hall: I ask whether the shaft in the flywheel motor-generator set is one continuous shaft or whether there are certain couplings; if so, how many couplings there are? Of course, upon that point rests the possibility of dismantling a set for repairs, in case of an accident.

The arrangement of the generators in the flywheel set I notice is different from the arrangement of the motors, so far as the commutators are concerned, and in one case the commutators are adjacent to each other, and in the case of the motors the backs of the machines are placed towards each other. I ask whether there is a particular advantage in the arrangement of the generators in this manner? I also ask if either the motors or the generators are supplied with air from blowers?

The question of rapid reversal of the generators is, of course, of great importance, and I note that the reversal is given, I believe, as 22 reversals in one minute, if I am not mistaken. I ask if the motors reach full speed in such a reversal as that, or whether that is simply the motors reversing as fast as they can, coming up to a few revolutions, and reversing before they can reach full speed.

In regard to the excitation of the generators, I understand that is 250 volts excitation in the field; that is, the exciter is a 250 volt machine. In order to get rapid reversal I presume the actual voltage on the field of the generator is probably very much lower than 250, and I would ask what voltage that is, normally; what is the normal voltage across the field of the generator running at normal speed and normal voltage?

The surface speed of the commutator is mentioned as being very high, and the fact that it is mentioned naturally brings about the question as to what the speed is.

In regard to the reversing motor some precaution is undoubtedly necessary to insure that the windings will not shift due to the reversal, and I ask in what manner the windings on the armature and commutator sets are braced to withstand the rapid reversals?

Wilfred Sykes: Mr. McCormick made the statement that the motor unit was divided into two machines so as to reduce the inertia. I have made investigations as to how much the inertia can be reduced by dividing it in two units, and find there is very little difference. The trouble, however, is if you use a single machine it is very necessary to go to very high voltage in order to reduce the current, or you run into difficulty with the commutators.

As far as the connection of the generators and motors are concerned, it has been my experience it makes very little difference, when you have two generators and two motors, whether you connect in parallel or series, so far as the division of the load is concerned. I ask Mr. McCormick whether the output which is mentioned, 75 tons per hour, has been obtained over any period of time, such as a day, or something of that sort.

There is one point in connection with the control of the set that I will call attention to, and that is the overload trips. As far as I can make out, the only overload protection is a relay in the armature circuit which opens the field circuit of the exciter. I would like to know what protection is provided for from sudden overloads which are liable to come with a cold ingot, or if the rolls are set down too far. It seems to me the overload trip is rather a roundabout way to protect the machines against overloads and make them immune to excessive fluctuations. For ordinary overloads this arrangement is all right, but I believe in addition thereto there should be an overload circuit-breaker provided in the main circuit which will open independently of this device which is mentioned.

There is another question I will ask Mr. McCormick, and that is in connection with the starter. Would not it have been preferable to have adopted a liquid controller, not only for the starting but also for the slip regulation, in the first place? That would have avoided the necessity of having magnetic switches and a water-cooled starter. I think the thing could have been very simply arranged so as to combine these two functions.

R. A. Black: The flywheel is stated here as being made in three sections of cast steel belted together. I would like to know whether this is a better construction than the laminated construction, and if so, what are the advantages of having it this way?

Speaking of the rapid reversals of the motor, I have had several cases of high-speed motors, and some very rapid reversing motors which gave a good deal of commutator trouble. I took the commutators and turned out grooves back of the brushes on either side, so that the brushes bore on just one surface, that is, there was no surface beyond the bearing of the brush, and I found by doing this that the commutator wear was reduced a great deal. In reversing the motor, there is always more or less tendency towards a little lateral motion, especially in high-speed reversing

motors. High-speed motors running continuously which have in the past given a good deal of trouble are now running with very little sparking. This may be objectionable to some, but I find it much better. The brush ordinarily runs in one path, and by so doing, wears the commutator down somewhat, leaving a ridge on either side of the brush, so that when you get the end thrust, you have a little ridge which raises the brush, causing it to spark; this makes flat places, and the more it runs the worse it gets.

H. C. Specht: I ask the author of this paper how many foundation bolts are in the bedplate? In Fig. 7, it seems as if there are only four to six bolts in total. Further, I ask whether the bolts through the pedestals are used also as foundation bolts, or if they only tie the pedestals on the bedplate?

I will also make a few remarks in regard to the size of flywheels. In this particular outfit as described by Mr. McCormick it seems that the flywheel is rather large for the capacity of that mill. It is generally claimed that the load on the induction motor of the equalizing set is practically constant. This, however, is in many cases due to the very large flywheel and not due to the automatic speed control. As a matter of fact the automatic control acts too slowly to catch always the short peak loads. If the automatic control devices would actually catch the peak loads on time, the size of the flywheel could be reduced to a great extent.

In many cases it may be recommended to connect into the secondary of the induction motor some permanent resistance, thus giving the automatic control more time to act, and the flywheel more chance to assist the motor immediately with the start of a peak load. Then, if desired, during the longer no-load periods, all the resistance may be cut out.

R. B. Treat: An equipment of similar nature was built for 250 volts, mainly because of the opinion of the Association of Steel Mill Engineers that 250 volts was about high enough. The large current was subdivided and delivered to several commutators in preference to one unduly large commutator.

Wilfred Sykes: I might say in connection with the voltage question that it is the usual practise in Europe to connect all the machines in series. I do not see the object of it where there are two generators and two motors. Where there is only one motor, or two motors, and there are two or three generators, then it is not possible to make the machine any other way, and the tendency in Europe has been to increase the size of the driving motors and concentrate as much power as possible on one machine, but, of course, in order to obtain, generators capable of running at a reasonable speed, so as not to have the flywheels too large, smaller units have been used for the generators than for the motors. Some of the latest installations in Europe are using single motors in which the maximum capacity goes up to 15,000 h.p.

As to the question of inertia, it does not make much difference whether you put it in one or two units at the present time. Four or five years ago the design of the machine was not as well understood as it is now, and then it did make an appreciable difference. In the first installation put in at Hildegradehuetts in 1906 there was a great advantage obtained by subdividing the motors, but with the present design it does not make much difference.

H. W. Cheney: I think I have little to say regarding Mr. McCormick's paper except to call attention to the fact that the starting resistance is quite unique and I should think could be comparatively small. The dimensions of the resistance are not given in the paper and I would inquire the approximate size of the resistance. It appears that the arrangement is such that a very large amount of energy should be dissipated with a very small element.

Bradley T. McCormick: Mr. Hall asked whether the shaft is made in one piece or in several pieces. The motor-generator set has one long shaft without any couplings.

He also asked why, on the motor generator set, the commutators are facing each other, while on the mill motors the commutators face away from each other. In the case of the motor generator set the two rotors are more accessible, for pressing onto or removing from the shaft, than they would have been if the commutators were turned the other way. On the mill motors I do not think it vital which way the commutators are turned, but probably from the standpoint of appearance the machines look better the way they are, with the armatures close together and the commutators on the outside. There are no blowers anywhere on the apparatus, neither on the generators, motors or induction motor.

The motors reach full speed on the reversals, and the test was made by throwing the controller handle back and forth as fast as it was possible to reverse the motors, the speed being read from the electrical speed counter. It was found that there was a lag in the response of the motors to the movement of the controller, so it was necessary to throw back the controller handle when the speed reached about 60 rev. per min. I made the test as above, and got eleven reversals in a half minute, from 75 rev. per min. in one direction to 75 rev. per min. in the other direction, which corresponds to 22 reversals per minute.

A point was raised as to the voltage across the generator fields. Full voltage, of course, is not on the fields. A certain amount of it is dissipated in the rheostat, but just how much is on the field I should not care to answer. Concerning the commutator speed of the generators, I did not intend in my paper to give the impression that the commutator speed approached that of a turbo-generator. The commutator speed is 3,500 feet per minute, which is no higher than commutators of motor-generator sets are usually run.

As to the matter of bracing the coils, I should rather not discuss that here, as it is an improvement of our own designing. We have gone very thoroughly into the question of bracing, and have secured the coils to the end heads or coil supports.

Mr. Sykes asked whether the full output of 75 tons an hour had been attained. Practically it has; I think, though, it is nearer 70 tons—70 tons seems to be about the run of the furnaces. There is no reason to think that 75 tons could not be obtained if it was desired to run the mill at that rate. Mr. Sykes also asked whether there is any additional overload feature. There is none, except the overload feature operated by the no-voltage relay on the exciter circuit. It will be, however, a very easy matter to put current trips on these, if it should be found necessary.

The question of a liquid controller has been brought up, and I see no reason why a liquid controller could not have been used to advantage on this system. It is of course a question of choice of a liquid controller vs. cast iron grid resistances, and this is largely a matter of personal taste.

Mr. Black asked whether it is better to have a flywheel cast in three sections of cast steel, than a laminated one. The flywheel in this installation does not revolve at such a speed that the strains set up in it are too great for cast steel to safely stand. The laminated steel flywheel is stronger, but of course much more expensive. By making the flywheel in three pieces comparatively light steel castings are obtained, which are not apt to contain imperfections. They can be fitted together with reamed bolts, and for all practical purposes they constitute a solid flywheel. Mr. Black also suggested grooving the commutator in order to do away with difficulty due to end play, resulting in the wearing away of the brushes on the extreme inside ends of the studs. This matter we have taken up, not because we have had any such trouble, but I think the suggestion is a good one.

Mr. Specht asked how many foundation bolts we have. I do not remember, but will say that there are enough, and that the machines are well grouted in, so that the concrete comes almost level with the top of the base. The pedestal bolts form the top part of the foundation bolts. I agree with Mr. Specht that the flywheel is somewhat larger than necessary, but it was our intention to design this set along very liberal lines, and we intentionally made this flywheel large, to be on the safe side if the controlling apparatus should not quite fulfill our expectations.

There seems to be considerable discussion on the subject of voltage, and I am unable to understand why there should be so much criticism of 1200 volts when the neutral point is grounded. I suppose everyone realizes that if one should go over the system with a voltmeter he would be unable to find any point on the system where he could get a voltage to ground more than 600 volts; this is no more than would be obtained with a 600-volt

parallel system with one side grounded, and the grounding of one side of a system, as everyone knows, often occurs without anyone finding it out until a ground occurs somewhere else on the system. However, with the middle point connected to the earth by a good heavy ground wire, if a ground does occur any where else in the system it will be burned off immediately.

The system which I have employed for the Algoma Steel Company has no more tendency towards overstraining the insulation by the working voltage, than the standard street railway generators which have been in use for so many years, where 600 volts or more is employed with the negative side grounded. Also, the liability of injury to operators by shock is no greater than met with in street railway practise.

Mr. Cheney asked as to the size of the water-cooled resistances. These resistance tanks are about three feet in diameter, and five feet high, and are quite liberal in water capacity. They hold enough water to start the motor-generator set several times, without replenishing the water.

Discussion on "Electrical Control of a Large Mine Hoist" (Cheney), Pittsburgh, Pa., April 27, 1912 (See Proceedings for March, 1912.)

(*Subject to final revision for the Transactions.*)

H. M. Gassman: I have had an opportunity to examine critically this installation. I can confirm all that Mr. Cheney has said in regard to the operation. I wish to emphasize particularly the smooth acceleration obtained. There was absolutely no noticeable jerking or impulse given to the rotor in starting with this type of control. Furthermore, I made it a special point, from the operating end, to inquire into the maintenance of this type of starter, and I was told by the man responsible for its operation that it is practically nothing.

W. O. Oschman: Is the air clutch for any purpose other than allowing the cars to drift into the mine when the hoist motor is stopped, and is the maintenance of this clutch excessive?

I would also like to know if a slack cable device is used on this hoist which will automatically stop the hoist when cars are being lowered into the mine, if for any reason the cars become derailed or are otherwise accidentally stopped.

H. E. White: The paper presented by Mr. Cheney is of unusual importance in that it shows clearly the possibilities of a type of control hitherto little used in this country but which is in Europe a recognized standard for large induction motors driving mine hoists.

One is greatly impressed with the simplicity and reliability of the whole thing as compared with the systems of control with magnetic switches which are the nearest equivalent. About the only adjustment requiring care is the maintenance of the proper saturation of the electrolyte and this would not seem to be very difficult. Some losses in the water would occur but these could readily be noted and the deficiency made up.

It is to be presumed that Mr. Cheney is familiar with some of the means which are in use elsewhere whereby a very quick emptying of the tank can be accomplished. In the application described this does not seem necessary, but in some cases the time of emptying, given as ten seconds, would be too slow. An almost instantaneous emptying is sometimes secured by using weirs that cover all of one side of the tank and which can be lowered very quickly to allow the electrolyte to escape. This arrangement would be necessary where a quick reversal of the motor is required. The use of compressed air as described in Mr. Cheney's paper would seem adverse to the very quick opening of the weir. The quickest results could be secured where the weir is carefully balanced and is controlled directly by hand. When properly made such a weir will not require a very great manual effort.

In designing a water rheostat there is some difficulty in getting proportions that will result in a small slip at full load, it being impossible to quite reduce the minimum resistance to zero.

Considering the other advantages this should not be serious enough to lead to its rejection.

In conclusion the writer wishes to express his belief that the water rheostat will meet with greatly increased use in this country.

Wilfred Sykes: The application of the brake by means of a solenoid which will open the air exhaust is the usual practise with European manufacturers, and to my knowledge it has been used since 1900 as part of the regular equipment of two principal European electrical manufacturing concerns.

Mr. Cheney drew particular attention to the limit switch, and I would like to point out that limit switches on any alternating-current hoist to trip when the cars pass a certain point are useless as far as concerns protecting the equipment against damage. The reason is that in order to allow the cars to approach the surface or the tipple at a slow speed the limit switch must be set beyond the dumping point. If for any reason, however, the operator fails to cut off the current from the motors and the cars are running, as in this case, practically on level track, the inertia in the moving part is sufficient to carry them on to the head sheaves. From the illustration it appears there is not a very great travel allowable beyond the dumping point, and if the operator should fail to cut off the current at the right place or slow down properly, it is possible to wreck the whole outfit. To overcome this, a patent has been taken out in England for a device which arranges the control in such a way that if you do not slow down at the proper rate, when you are approaching the surface, the brakes will be applied; assuming you start to slow down 50 ft. from the surface, and you run that distance at rather high speed, the brakes will come on before the cars reach the surface. On the other hand, if you slow at the proper rate, the prescribed rate, this apparatus does not come into play and nothing happens.

In the description of the liquid controller, and it seems to me that this is the principal item in this hoist, it is stated that the electrode tank is concrete lined. I would like to ask why that is done. An experience over a great many years, with a liquid starter, has demonstrated to me that if you do not have an electrolyte that is corrosive a plain iron tank is very satisfactory, and I know of a great many starters that have been used for seven or eight years, and there has been no trouble from the tanks being eaten through.

It is not quite clear why the electrodes were arranged in the way they are, with cross plates between them in order to increase the area and reduce the effective distance between them. It seems to me the obvious arrangement is to have a number of vertical plates, and you can have these of different lengths, so that as the liquid rises the resistances are readjusted in the proper way. It is not necessary to have the electrodes so far apart as shown in Mr. Cheney's paper, nor, in my opinion, is it necessary

to work with this low current density. I have repeatedly run liquid starters in which the electrodes were not more than a half inch apart with current densities up to ten amperes per square inch, and you can do that for short periods, such as will be required in the acceleration of a hoist of this kind, provided you have the forced circulation and the liquid flows rapidly between plates. If you have a stationary liquid, and no forced circulation, then you cannot run the density so high, but there is no difficulty in running it up to 10 amperes per square inch for other purposes. Usually, it is a good deal lower than that.

I would like to ask why salt is adopted. My experience has been that common washing soda or carbonate of soda is about the most satisfactory electrolyte that can be obtained. It is cheap, and a good many tests have shown that the corrosion with this electrolyte is a good deal less than with anything else you can obtain. I would like to refer to some tests published in the *Electrotechnische Zeitschrift*, about four years ago, which go very completely into the question of corrosion of the electrodes with different electrolytes, both for direct current and alternating current.

This apparatus seems to me to be very large for the amount of work intended to be performed. There is no dimension given of the size of the cooling tank. As far as I can judge, it seems to be five feet wide, but the length you cannot tell; but for the amount of energy that has to be absorbed by this starter, this seems to be very large indeed, especially the electrode tank. I have repeatedly started motors up to 1000 h.p. on starters in which the electrode tank was only about 24 in. square, and the electrodes immersed about fifteen inches in the water. As a matter of fact, with some of the European concerns, it is more or less standard practise to have that proportion. You can run the starter much harder when you have forced circulation than you can in this case.

The question has been raised as to the time required to empty the tanks. No doubt in this installation the quick emptying of the tanks was not necessary, but if you have a vertical hoist where it is quite often necessary to plug the motor in order to protect it, you must be able to empty the tank almost instantly, and I should set a limit of not more than two seconds as about the maximum which you can stand for any vertical hoist in order to obtain proper control. It would be absolutely out of the question for it to be necessary to take 10 seconds for any fast work. In this case probably 10 seconds is all right for a slow hoist.

The last discussion I think pointed out that in order to get quick operation of your hoist the best arrangement would be to have the weirs manually operated. I think if you design the starter properly you can work this all right. The addition of air cylinders and the various lever arrangements described certainly must increase the cost of the starter quite appreciably, and also it gives so many parts that may possibly give trouble.

Mr. Cheney stated that there was very little information available when he started to design this controller, regarding liquid starters. There is a good deal of information, however, which has been published in the German papers like the *Elektrotechnische Zeitschrift*. There have been quite a number of articles in that publication on this subject, and they have given a large amount of detail information as to the practise of various European manufacturers.

Regarding the question as to the capacity of the rheostat, which Mr. Cheney pointed out—in this case they used the number of watts that could be absorbed per cubic inch—my experience has been with a starter of this kind that the energy absorbed is taken care of by the evaporation of the water, and if you have forced circulation with an open electrode tank as you have here, you can put in about two or three times as much energy for the same volume of water, the same temperature rise, as you can if you have not the forced circulation.

Of course, if you have cooling coils you can practically take care of almost the whole of the energy in the cooling water, although, in such case, when you are pushing the rheostat very hard, a great deal of it is lost by evaporation, but it does not necessarily mean that a great amount of water is evaporated, on account of the fact that if you evaporate water it takes something like 900 B.t.u. per lb., which will take considerable energy.

Mr. Cheney stated that the rheostat control was inherently uneconomical in the place where it is, but not always for hoist work; in fact, in a great many cases, especially where the hoist is only worked to a limited extent, or where the hoist speed is low, or the accelerating period is comparatively a small percentage of the total running period, then the rheostatic control will be found to be the most economical that you can have for a hoist. Where you have very rapid operation, high speed and short lift, then some other system, such as the flywheel motor-generator system, or just the plain motor-generator system with voltage control, would probably be more economical; but generally it will be found that the rheostatic control is the most economical arrangement for the average hoist.

F. L. Stone: I have read with considerable interest Mr. Cheney's paper on the control of a large mine hoist, and there are several points which I would like to discuss. Mr. Cheney states that the design of hoist apparatus must be such as to withstand most severe and unreasonable conditions of service. I cannot understand, when the duty cycle is given, why there should be any difficulty in the proper design of the control and hoist motor. It seems to me that we know more about the loads to be imposed on a hoist motor than almost any other line of motor application and therefore, when the proper use of this knowledge is made, there should be no failures in electric hoisting.

In regard to the particular hoist described, Mr. Cheney advised that the gearing was the triple reduction type. I am inclined to believe this must be a misprint as the gear reduction from the motor to the drum is only 8.5:1 and could be economically obtained by one reduction. If there are three reductions as stated, I would like to inquire why, since this must of necessity make the friction losses excessive.

In regard to the design of the liquid rheostat proper I note there are but four plates used and to these plates in the upper ends are bolted additional plates for increasing the area of contact, and that the plates proper are made of cast iron. With this arrangement I can readily conceive the difficulty of having the phases balance during the acceleration period. Would it not be better to use a multiplicity of plates in parallel on phases, such as say twelve or fifteen? This reduces the chance of unbalancing the phases very materially and gives a very large area of contact. These plates can be tapered if so desired.

I further note that it takes 10 seconds to empty this tank and approximately 20 seconds to fill it. It would seem to me that if quick reversals were called for in emergency conditions, this slow emptying of the tank might produce very injurious results, as the motor would be reversed to the very lowest resistance in secondary.

I note further that sodium chloride had been used in the electrolyte. Experience has shown that the use of sodium carbonate gives much better results in that there is no active gas such as chlorium liberated, and the life of the plates is much prolonged. I might further ask, why cast iron plates are used in the place of sheet steel, the latter being much more readily renewed.

Fig. 13 shows the operation of this hoist very clearly and there are several features in connection with these curves about which I would like to ask information. First, I note from the revolutions per minute curve that it takes approximately 60 seconds for the hoist to reach running speed. This would seem to me an excessively long time to accelerate such equipment. Further than this I note that the hoist does not reach running speed until the trip is past the knuckle and the load fallen to approximately 125 kw. It would seem to me that this points to excessively high resistance in the liquid control. This point is further exemplified by the fact that from the revolutions per minute curve the slip in the motor, due to the resistance of the controller and the resistance of the rotor, is approximately 10 per cent with only 100 kw. output. This further points to very high resistance in the control. Liquid rheostats are working satisfactorily with but 5 per cent slip at full load, of which approximately 2½ per cent is due to control resistance and 2½ per cent due to rotor resistance.

I note that the maximum speed called for is 750 ft. per minute, while the average speed, as closely as I can determine from

the curve, reached 450 ft. per minute. This means slow production.

I would be glad to hear Mr. Cheney's comments on these points as they are of vital interest to electrical designers. The liquid controller is becoming more and more popular daily and within the next two years there will be a great many of them installed in this country.

Wilfred Sykes: There was one point I intended to mention, and that is the specific resistance of the electrolyte is practically of no importance, because if you have the distance between the electrodes properly arranged in the right proportion it does not make very much difference what the specific resistance of the electrolyte is; because this can always be arranged by adding more or less salt to the water. In fact, you have to do that anyway, because you cannot get any fixed formula for the amount of salt required, owing to the variation of the water in various localities, so that the main thing in the designing of a starter of this kind is to get the areas and proportions of the electrodes right.

E. Friedlaender: I wish to ask how much the efficiency of this installation could have been increased by using a smaller motor which could have done the work just as well.

H. W. Cheney: In reply to Mr. Oschmann's question, I will state that the air clutch is simply used to disconnect the drum from the driving members of the hoist to allow the cars to lower into the mines. There is no slack rope switch provided in this installation.

Mr. White points out that the quick opening of the weir is sometimes desirable. Mr. Sykes also mentions this point. In quite a good many installations, I agree, it would be extremely important that an opening through the weir or possibly an auxiliary opening be provided, so that the electrolyte can escape very quickly.

Mr. Sykes mentions a limit switch and states that in an installation of this kind a limit switch would be practically useless. As a matter of fact, I know that the limit switch has in several instances operated and has stopped the hoist in a very short distance. I do not know that it has operated at the extreme outward travel of the tipple, but I am informed by the men down at the mine that the limit switch has proved satisfactory. I have not been on the ground, of course, to see just what did take place.

Mr. Sykes mentions concrete and wants to know why concrete was used. As a matter of fact the concrete was adopted, not because it was a particularly better design than any other material, but partially because the people who were installing this apparatus were willing to build the tank right in the hoist house, and we did not see any reason why the concrete would not be satisfactory, and it has proved satisfactory in operation.

Mr. Sykes mentions that he has had experience in operating

liquid rheostats of up to 10 amperes per square inch. That is quite possible, that is, for intermittent periods, and I think that it was not the intention of this paper particularly to limit the amperage to three,—of course, we should be guided by the nature of the intermittent service. I have said from one to three amperes—one ampere for continuous service, and three amperes for intermittent service. Intermittent service is a term which may have one meaning in one case and may have quite another meaning in another case. If the service is quite frequent, then I would say it is better to hold the area, that is, the amperes per square inch, down to somewhere near the limit given.

Mr. Sykes also asked why salt was adopted. I believe I mentioned in the paper that we found a number of different solutions which would probably be satisfactory, but that we adopted salt because we found that it worked satisfactorily and it was readily obtainable, and people are familiar with it, and they are always able to get salt when it is sometimes impossible to get some of the other materials.

I wish to say, in regard to the electrode tank being large, that I agree with Mr. Sykes that this tank might have been made smaller. This was the first liquid rheostat that I have had anything particular to do with in the way of designing a controller for regularly operating a large induction motor, and I have found, since the installation of the apparatus, that we were on the safe side by a considerable amount. We might have made the tank smaller.

In regard to operating the weirs manually, I would also say that that can be very readily accomplished, in fact, it is being accomplished in other later designs. This plant was designed some time ago, and the description given in the paper, while it is not intended to show the latest design for controllers of this type, was intended to show a type of liquid rheostat that has proved very satisfactory. I quite agree that the forced circulation of water through the rheostat tanks increases the capacity of the electrolyte to absorb energy.

With regard to Mr. Stone's point, of course it is quite impossible to cut out all of the slip with this form of controller, and where the controller is running for a large portion of the time at somewhere near full speed it would also be quite desirable to provide means of short-circuiting the rings of the induction motor in addition to the final point of the liquid rheostat. That can be easily accomplished by an auxiliary switch. However, in this particular installation the trips at the present time are comparatively short.

Mr. Friedlaender asks why a smaller motor could not be used. As shown from these curves it would appear that a much smaller motor might have been used. As a matter of fact this mine, at the time these tests were made, was not developed to anything like the extent that it will be developed, we expect, in the future.

As the depth of the mine becomes greater, it is anticipated the load will be increased materially. The motor we have found to be satisfactory and amply large, but in line with the discussion of some of the papers yesterday, we prefer to be on the safe side in specifying motors of sufficient capacity to take care of the heavy loads which are obtained in pulling up around the curves when the loaded cars become derailed.

DISCUSSION ON "VACUA" (WHITNEY), BOSTON, MASS., JUNE 25, 1912. (SEE PROCEEDINGS FOR JUNE, 1912.)

(*Subject to final revision for the Transactions.*)

A Member: Dr. Whitney refers to the gases which disappear from the incandescent lamp, and refers to the same phenomena in connection with the X-ray tube, and he calls attention to the fact that some of these old glasses from the old bulbs, either from the incandescent lamp or from the X-ray tube, bubble on being heated to the softening point. I hope that Dr. Whitney will clear up the claims of certain English physicists, and of German physicists, as to this matter. Dr. Robert Poole of the University of Berlin repeated some experiments made by an English physicist and he declares absolutely that the Englishman is mistaken; that an old glass does not give off this gas when it is under pressure in a vacuum so that the gas would be given off. Dr. Whitney refers to the fact that the glass when heated to a softening point will bubble, referring to the old glass, and I know a new glass does this as well, the conditions being that the old glass or new glass must be in a vacuum of something less than one millimeter actual pressure. I hope that Dr. Whitney will clear up this point, because the question of where the gas goes to is really a question that is important.

W. R. Whitney: I don't want to try to clear that up yet, because we don't know enough. There are various theories about it, but I cannot decide it.

Alfred H. Cowles: In a letter from A. H. Bucherer, of Bonn University, it is stated that in Europe they have a new method of creating a much higher vacuum than anything heretofore secured. I do not know whether that method is known in this country.

W. R. Whitney: As a further contribution to the question of gases within the glass of old X-ray tubes, lamps, etc., I will add that such gas also appears in the glass of old mercury rectifiers. Mr. Van Brunt, of the research laboratory, heated in a blast lamp the glass side-arms of old mercury rectifiers. The portions of the glass near the anodes turned white. On microscopic examination it was noted that this part of the glass was filled with minute bubbles which were not there prior to the heat treatment. They were within the glass itself, though much nearer the inner surface of the tube than the outer. This was shown by grinding and polishing in a plane which made a very acute angle with the surface of the glass. We did not consider the appearance of these gases in such glass an open question, but believe the question now is as to the source of the gas. Are these bubbles produced from gas which was dissolved or driven into the glass during the operation of the lamp or tube, or was the gas produced by a reaction between some injected material such as the electrode material and the material of the glass, or was it produced by the action of leakage current, static, etc., which caused a sort of electrolysis of the glass, the gaseous products remaining dissolved until the glass was subsequently heated?

DISCUSSION ON "CHARACTERISTICS OF A LARGE UNIPOLAR GENERATOR" (LAMME), BOSTON, MASS., JUNE 28, 1912. (SEE PROCEEDINGS FOR JUNE 1912.)

(Subject to final revision for the Transactions.)

J. E. Noeggerath: It is a great pleasure indeed to congratulate Mr. Lamme upon his frank and exceedingly important paper on acyclic machines, and to comment on it, as naturally having been in a position to overcome similar difficulties in the development of the unipolar machines I am connected with, I appreciate the extraordinary problems that have to be met.

A few of the troubles mentioned by the author did not materialize, as those connected with the slots for the conductors, since the machines were built differently from the start; also the rings never came loose, but, as fair exchange, experiences were bought dearly in other ways. Of the problems in common some were solved in the same manner, some entirely differently, by which statement I do not lay claim to a better solution.

Mr. Lamme's design of the collector rings is ingenious. He states that one of the reasons for building them up out of two

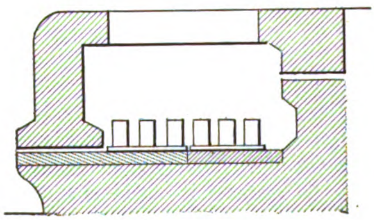


FIG. 1.

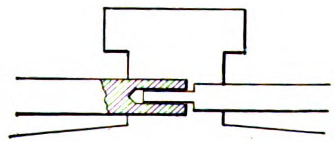


FIG. 2.

concentric rings was to facilitate their exchange. A different way of solving this difficulty is not to mount the collector rings on the armature directly, but rather *on a separate shell* which, magnetically, forms part of the armature. (Fig. 1). This eliminates the necessity of handling the heavy bulk of the armature, reducing the weights that have to be taken care of in shipping and dismounting, to considerably less than 10 per cent.

The collectors are so designed that one-half of the rings can be taken off from one end and the other half from the other end. In case of a large number of rings two or more collector shells are used for each set.

Due to the length of the conductors, it is necessary to provide in some way against the stresses produced by heat expansion. For the purpose of eliminating them, Mr. Lamme inserted a *flexible* element.

The corresponding solution which avoids the necessity of taking away space from the magnetic section, consists in *dividing the conductor lengthwise*, the end of one-half protruding into the

end of the other half (Fig. 2), or in providing a sliding connection, the conductor fitting loosely into a hole in the ring. Since the peripheral speeds are very high, this connection forms a perfect contact which has proven successful in years of operation.

Bearing troubles were solved in identically the same way by Mr. Lamme and myself, both of us using coils in the bearings to counteract the stray fields.

Part of the collector ring troubles too was taken care of in the same way, as in both cases soft insulated graphite brushes of a specific kind are used; if I am not mistaken, even the same make is used.

Mr. Lamme's investigation relating to the other brush troubles and supplementing my investigations of the theory of the electric contact are ingenious and I gladly acknowledge that where I have

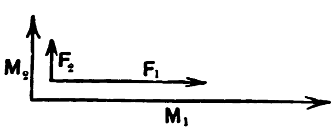


FIG. 3.

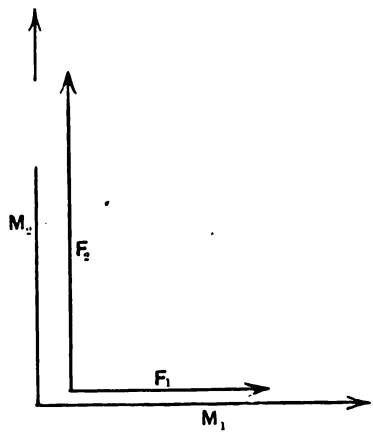


FIG. 4.

taken the first step, Mr. Lamme at the present stage has obtained superior results as to the voltage drop in the contacts. He succeeds in permanently keeping it down to an average of 0.4 volt; he even mentions 0.1 volt; these are excellent results.

I am glad to have Mr. Lamme a commiserator as to the mileage that has to be traveled over by the brushes. If such requirements had been fulfilled by single-phase commutator motors, the maintenance expense would have become reasonable long ago.

As to running the generator, *i.e.*, the rings against the brushes, it has been my experience for a long time that this is feasible; an additional advantage not mentioned but probably known to Mr. Lamme, is that in running against the brushes, a compounding action takes place.

If any criticism can be made outside of those mentioned by the author of the paper himself, it would refer to the great bulk

of the machine; this can probably be explained to a considerable extent by the comparatively low speeds employed.

As Mr. Lamme has brought up again the question of the magnetic fields of unipolar machines, I put now before the Institute the results of an investigation which originally I intended to elaborate into a paper.

I have found that, in contradistinction to the accepted ideas—this ought to be of fundamental importance with regard to the theory of the magnetic field—*magnetic fields set at right angles to each other do not affect each other in the least* (Fig. 3 and 4).

In other words, if a field is set up in a magnetic material which is permeated by a second field at right angles to it, the relation of the first field to its electromagnetic force is not of the slightest degree effected by the second field, although the second field may be so strong as to have completely saturated the iron at right angles to the first field.

If for instance in Fig. 3 *M*-1 and *F*-1 represent respectively a strong magnetomotive force and a strong, magnetic field it is natural that it will be little or not at all affected by a small second magnetomotive force and magnetic field etc., *M*-2 and *F*-2 set at right angles to 1.

However, it should be expected, according to the usual conception, that if *F*-2 and *M*-2 reach saturation (Fig. 4) then with the same *M*-1, *F*-1 should be considerably reduced because one should assume that if the iron is saturated in one direction of the field *F*-2 that there will be no possibility for any magnetic flux to pass through it even though directed at right angles.

However, *F*-1 is not at all affected by *F*-2. This is not in contradiction to the phenomena observed with fields which are said to be and are in some respects at right angles to each other in alternating-current machinery, in commutating direct-current machinery and even in many types of unipolar machines. (However, unipolar machines can be so designed that the fields are in such relation to each other so as to be actually at right angles. This is of course not usually the case when conductors are placed in slots or holes as in Mr. Lamme's machine). This is, as I stated, not a contradiction, as a close scrutiny will show that the fluxes in the cases usually considered are affected in their mutual relationship not because they are at right angles but for any of a number of other reasons.

These conditions seem to find a parallel in the modern theory of light.

In concluding, I take pleasure in stating that I have observed the successful operation of Mr. Lamme's 2000-kw. machine. It ran very well indeed; there was no sparking; it ran cool, noiselessly and without vibration.

It is almost needless to say that I hope the paper will give a new impetus to this development, which though apparently stagnant in the United States, I had the pleasure of reviving in Europe.

Elihu Thomson: I listened to Mr. Lamme's account of his experiences with the unipolar machine with much interest. It is an example of how bold an engineer must be at times even to undertake the problems of which so little is known. He enters the field and tries to do the work and then finds so many difficulties that it is a wonder he ever gets through or does not lose his enthusiasm before he has gone as far as Mr. Lamme has gone, I congratulate him on the final result in having a machine that will do the work. Now, in regard to unipolar construction, it will be recalled that in 1884 in the old electrical exhibition in Philadelphia George Forbes showed two or three examples of unipolar dynamos. They had great blocks of carbon for brushes, but it is about the worst material to be used in the case of a unipolar machine where the contact resistance is high. The loss involved would be very great. About 1885 or '86 we were studying the problem of the possibility of large power stations for continuous work, from the point of unipolar design, thinking possibly we might construct a number of machines in series for a very large output such as 25,000, or 30,000 kilowatts, large in those days. I was led to look into the unipolar design. I built two machines of moderate size to test out the conditions, the armature conductor was single without series connection. This single conductor was used much as in Fig. 2 of Mr. Lamme's paper, only the compounding which I obtained in that machine was by making the current collecting ring connect with the inner conductor by a spiral band going around two or three times, as if a huge ribbon had been wound around, which carried the current to the outside ring. That is simply doing the same thing as carrying the leads from the brushes around in order to get compounding. The machine, however, developed difficulties and it was evident that we did not have enough knowledge in those days for proper construction. The iron losses were evidently, however, quite low. I would say that the rotor itself was composed of a plain cylindrical bar which was evenly plated with copper on the outside so as to confine the conduction to the outside, and in the air gap. I was led to suspect in those days that possibly there was a lessened loss to be expected in iron, where we did not have a reversal of flux, and in building some inductor dynamos later we found the iron losses so low that they were hardly measurable because the flux merely changed direction from one point to another, so that the amount of iron subject to magnetic changes was very small. That I think would apply in the case of unipolar machines and account for the low iron losses.

I was interested to note the remarks that Mr. Lamme makes as to the brushes. This problem in a way reminds me very strongly of the early days of railway motors. We had a hard fight to get railway motors to work in the street, where they were exposed to the dust and dirt of the street, and the commutators likewise. We attempted to run them open, without any boxes or casing, and encountered many difficulties. I was on the point of telling

our company to hold up on railway motor business because the commutator repair bills would swamp them. We then introduced the carbon brush. The box type of motor kept the dust off, and our hard work was over. For a time it was a very serious outlook. I recall that in 1889 Mr. C. E. L. Brown, known to us all as one of the most competent engineers, whose work has stood as the very highest, was engaged at that time in unipolar design, and the Oerlikon works had a contract to build a machine for 10 volts for electrolytic work. It was of large output, something like 12,000 or 15,000 amperes. I saw the parts of the machine in the shop. The rotor was a large copper pulley with rims turned up at each side for the traverse of the brushes. I said to Mr. Brown, "That is all right; but how about collection of current from that ring? The wear will be terrific on those surfaces and your ring will soon have the flanges worn off." He said "Do you really think so?" I said "I know so. I don't believe it is possible for you to run at those high speeds without wearing them off." In about a year's time a letter came from Mr. Brown saying he had found exactly what I told him about the brush wear was true, and he said "Now I am going to try carbon." I wrote back that I thought he would be in worse trouble with carbon than with leaf brushes because the leaf brush will accommodate itself to the surface while the block of carbon will dance and jump, and cannot possibly follow the vibration of the machine unless the pressure be so high as to cause a mechanical friction that will be absolutely prohibitive. Later on I heard from Brown that these things were true. I have been interested very much to see the chemical methods of keeping contacts clean as applied in the way that Mr. Lamme says has been done. When I was analytical chemist, to keep our metal surfaces clean we washed them with a little hydrochloric acid. If applied to cases of the kind in such a way that the acid would not do any damage around, it would often solve difficulties.

W. L. Waters (by letter): Mr. Lamme, at the end of his paper, states—"As an example of engineering pertinacity, this machine is possibly without a rival." I would change the word "possibly" to "probably." The writer had the pleasure of assisting Mr. Lamme in some of the work described, and I think that engineers that have been through similar difficulties will realize that his bare narrative covers a long period of strenuous work—work that would never have been brought to a successful conclusion, but for the extraordinary resourcefulness and perseverance of the man who was directing it. As stated in the paper—"It might be said......................that many of the troubles encountered with this machine could have been foreseen," but when it is considered that this is merely one of a thousand machines that were being handled in the routine work by the engineers responsible for this unipolar machine, it is easily seen that the only way to decide the numerous points which arose was by the direct experiments described in the paper.

Apart from any commercial value, the final placing of this machine in successful practical operation was an education, both moral and technical, to the engineers interested, such as can rarely be obtained; and I think the Institute is very fortunate in having such an impartial narrative placed among its records for the benefit of those who are able to appreciate such development work.

DISCUSSION ON "THE APPLICATION OF AUTOMATIC SELECTING DEVICES TO TELEPHONE MULTIPLE CIRCUITS" (DYSON), PORTLAND, ORE., APRIL 17, 1912. (SEE PROCEEDINGS FOR MAY, 1912.)

(*Subject to final revision for the Transactions.*)

The Chairman: I would like to ask Mr. Dyson if it is the plan to distribute a call to the first idle operator, or the first idle cord.

A. H. Dyson: It may be the first idle operator, or you may arrange it so that the calls for a particular operator will be distributed between thousands of lines, or hundreds of lines.

Gerald Deakin: I want to assume this; suppose two calls are coming in almost simultaneously, the first call would reach the first cord, the second call may go to the second, or the first idle cord, and further on there may be other idle operators who would really give much quicker attention to the call. Is there the possibility of several calls coming in almost at the same moment being loaded up before one operator?

A. H. Dyson: The system is capable of being arranged either way; also it is so arranged that a call will appear before an operator only when she is idle, but I don't think that is a good arrangement, because it enables the operators to loaf on their jobs. I believe that the loading of an operator will only occur at the beginning of business. After that, calls will appear before the operators in rotation and will be taken down in rotation. An operator is placed in connection with the calling subscriber if she is not already busy, in approximately one-half a second after removing the receiver from the hook.

H. M. Friendly: Mr. Dyson's paper deals with certain apparatus to reduce the number of answering jacks. I ask if he has ever considered reducing the number of multiple jacks by the use of such equipment?

In private branch exchange work that requires that two or more trunk equipments be provided at the central office, it is often necessary for the operator to successively test all of the trunks of a particular private branch exchange, or exchange subscriber before she finds a disengaged trunk, or finds that there are no disengaged trunks. This requires time, and the consequent clicking due to such tests is more or less annoying to the calling subscriber who may be holding the line in waiting for the called party. The greater the number of trunks, and the more busy the private branch exchange, the more serious this trouble becomes. This is aside from the fact that a great many multiple jacks, each appearing at every section, are required for this service. It has occurred to me that by installing a sub-multiple—and that multiple appearing at only one, or say at the most, three positions, and then associating these various sets of multiple or individual jacks with automatic trunk selectors that have access to all the trunks of the private exchange the operator would be relieved of all testing, and the delays

and annoyances incident to it. She would simply plug into either of her several individual jacks without testing, or if jointly used by several sections in multiple to test a relatively few jacks before finding a disengaged one. The selector equipment could obviously be arranged to signal directly by auditory means to the calling subscriber, or by visual means to the operator, if all the trunks are busy. I would be interested in knowing if any such scheme has been contemplated.

A. H. Dyson: I will answer by saying that each private branch exchange trunk may be equipped with a selector switch. And the private branch exchange jacks instead of being multipled through the various sections of the board, may be individual to each section and connected to the bank contacts of the switches. The operation being such that an operator on receiving a call for a private branch exchange plugs into any one of the jacks on her section assigned to the particular private branch exchange wanted, which act causes the switch of an idle trunk line to select the jack plugged into by the operator.

This arrangement saves a certain percentage of jacks required on each section and also obviates the necessity of testing the private branch exchange jacks until an idle trunk is found.

Gerald Deakin: Would that not require a separate jack in each section rather than a jack multipled through all sections?

A. H. Dyson: Yes, at the present time you have a number of jacks to each section equal to the number of trunks leading to a private branch exchange, and instead of connecting these jacks in multiple you make them individual contacts with the switches associated with the trunk and multiple the jacks on the switches.

Gerald Deakin: That would not be very economical in the larger exchanges, for example, you would have 30 switches or contacts for each trunk in an exchange of thirty sections.

A. H. Dyson: Take two switches on two trunks connected 100 sections. You would employ two 100-board switches and you would use about the same number of multiple jacks you now have.

Mr. Burghduff: I ask if your system contemplates the use of an individual selector for each subscriber's line?

A. H. Dyson: As stated in my paper, there is one arrangement by which it may be accomplished. The arrangement is to provide a series of switches common to a group of lines, say a hundred of them. We have ten 100-point switches taking off a hundred lines, and then upon the removal of the receiver, an idle one will be located to select the line better.

By having ten you could have ten full system connections as calling lines for each group; they can be continued to any extent you desire.

Arthur Bessey Smith (by letter): The method which Mr. Dyson has described, for handling telephone traffic, has been productive of considerable thought by a number of telephone

engineers, in the past few years. Various names have been applied to it, such as the following: "Automatic Traffic Distributor," "Automatic Call Distributing System," and even "Semi-Automatic," although the last term should not be encouraged. In general, the writer concurs with the conclusion reached by Mr. Dyson, but feels that several points might profitably be more fully expanded.

The manual telephone switchboard operator works at her greatest efficiency during the busy hour, when the calls are coming in at their maximum rate for the day. As the load on the board falls off, each operator has less to do. Consequently, telephone companies attempt to maintain the efficiency of their operators by reducing the number at times of light load. Though obviously cheaper than maintaining the full force all day, it leaves much to be desired.

When an operator has to handle more than one position, she cannot answer calls as fast, since she must reach farther and with more effort on each connection. The reduction of efficiency is clearly shown by the curve in Fig. 1. Starting with a standard of 100 per cent as the load which she can handle at one position, she can care for only 73 per cent as many calls when two positions are assigned. For night work, when one operator must tend many positions, the efficiency is very low. Ten positions give us a load only 18 per cent of her full one-position ability. Thus the expedient of adjusting the number of operators to the load results in great loss of efficiency without making the work any easier.

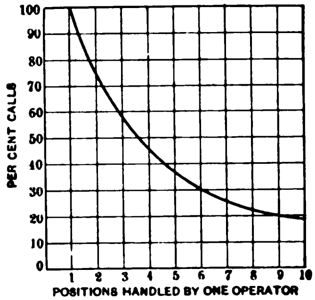


Fig. 1.

If the load curves of each of the positions on a board be examined it will be found that the busy periods do not occur at exactly the same time on all positions. This causes a further loss in efficiency. Fig. 2 was taken from an actual peg count and illustrates the inequality very well. From 6 to 7 a.m., position 9 is the only one to have an appreciable load. From 10 to 11 a.m., positions 4, 6 and 9 have an increased load, while 5, 7, 8 and 10 have very much less to do. The afternoon peak comes between 4 and 5 on positions 5 and 9, between 5 and 6 on positions 7 and 10, while it is as late as between 7 and 8 on positions 4, 6 and 8.

In general, the traffic manager aims to equalize the load by rearranging the lines at the immediate distributing frame so that as far as possible the busy time will be equalized. This is a matter of difficulty, for it requires constant attention and much thought and labor. Very few exchanges are successful in securing it.

There is another great loss of efficiency due to the evil of "rushes." For instance, when we say that 225 calls were handled by one operator in one hour we have only a partial idea of her speed. During that hour the calls did not come in an even, steady stream. There were periods of rush, when she may have been answering calls at the rate of 700 or 800 per hour, followed by short periods of slow calling or even idleness. The observations of experienced operating companies has shown that even during the busy hour, an operator is actually working only 50 per cent to 67 per cent of the time, the latter figure being unusual.

Formerly the only known method of reducing the inequality

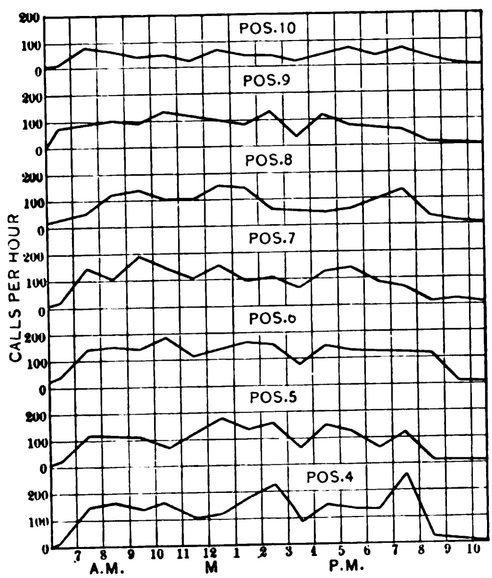


FIG. 2.

was "team work." Each operator is trained to keep lookout over the position to her right and left so that if her neighbor has more than she can do, assistance can be given. Though this reduces the evil a little, it still fails to get at the root of the matter.

The ideal condition in manual operation would be reached if there could be secured an absolute uniformity of load on all the operators. We could then reduce or increase the number of positions to suit the load, each working at full efficiency all the time. The momentary rush would lose its terror, being lost in the general average. Since one position is as busy as another, one has no necessity for helping another. The elimination of

the answering cord reduces her manipulations very materially. On a conservative basis it is believed that this will save about 22 per cent of the time required per call.

In addition to the 22 per cent saving in time secured by simpler operation, we have a large saving in the uniformity with which calls come to each operator. Under good operating conditions at ordinary manual boards, the operator is actually engaged only two-thirds of the busy hour. By means of the call distributor this can be raised to five-sixths, or at a loss of only ten minutes in the hour. This alone amounts to a 25 per cent increase in efficiency. The saving of 22 per cent in time per call means a gain of 28.5 per cent in efficiency, which taken in connection with the 25 per cent makes a total increase in efficiency due to these two causes of 60.6 per cent. This takes into account only the busy hour load.

Adjustment of Operating Force to the Work. It has been found in ordinary practice that the average number of calls answered by an operator is about 75 per cent of what she answers during the busy hour. This is known to be due to the loss of speed incurred by having one operator tend two or more positions. With the traffic distributor no operator ever has to tend more than one position, because as the force is reduced, the vacant positions are made busy, thus restricting the traffic to the occupied positions. Thus each girl may be held up to her busy hour load, so that no loss need occur from this source. This will add about a 33⅓ per cent to the operator's average all-day efficiency. The number of positions occupied can be in direct proportion to the total traffic.

Saving in Operators' Salaries. Since the operators' speed has been increased it will take fewer operator-hours to run the board. The increase of 60 per cent in busy hour efficiency mentioned above means a saving of 37.5 per cent in force, or a busy-hour force only 62.5 per cent as large as under ordinary conditions.

The increase of speed of 33⅓ per cent in all-day work means another reduction of 25 per cent of the operator-hours necessary to run the board, or a force equal to 75 per cent of the old force. Taking both these reductions into account makes the new operator-hours 47 per cent of the old. We may say, then, that with the automatic call distributor a manual board can be operated with less than half the operator-hours and less than half the operators that are now necessary with ordinary methods.

A Comparison. The advantages of the automatic traffic distributor over ordinary manual operation are most strikingly shown by direct comparison. In the following list the traffic conditions which reduce efficiency are given with the remedy which each system proposes.

General Hourly Variation

Ordinary Manual. Adjust number of operators to suit load. Greatly reduce efficiency at light load. Inferior service at overload.

Call Distributor. Adjust number of operators in exact proportion to load, each at full efficiency.

HOURLY VARIATIONS BETWEEN POSITIONS

Ordinary Manual. Use of intermediate distributing frame and team work.

Call Distributor. The difficulty does not exist—the load is equal on all.

MOMENTARY RUSHES, VARIABLE BETWEEN POSITIONS

Ordinary Manual. Team work.

Call Distributor. Uniform for all operators.

REDUCED EFFICIENCY WHEN TENDING MORE THAN ONE POSITION.

Ordinary Manual. Team work, but a very slight remedy.

Call Distributor. Difficulty does not exist, as each operator tends one position at all times.

From the foregoing it is seen that regarding every difficulty for which the ordinary manual has a partial and inadequate remedy, the automatic call distributor meets the issue squarely by removing the cause.

The automatic call, or traffic distributor, offers a very satisfactory intermediate step between manual and full automatic operation. If the human operator is to be retained at all, this system retains her services under the most favorable conditions. Those systems in which the operator is entirely cut off from the connection after it has been established, fail to secure the advantages of the much-talked-about human intelligence and personal touch. However, the writer is of the opinion that the human intelligence can be to advantage dispensed with, for the majority of telephone connections, and that full automatic will give a class of service superior to that of any other device which has so far been discussed.

DISCUSSION ON "CHARACTERISTICS AND APPLICATIONS OF VIBRATION GALVANOMETERS" (WENNER), BOSTON, MASS., JUNE 25, 1912. (SEE PROCEEDINGS FOR JUNE, 1912.)

(Subject to final revision for the Transactions.)

Jefferson E. Kershner: What is the method of reading the instrument?

Frank Wenner: The ordinary method of reading the instrument is to use a mirror on the moving system, and an arrangement giving a line source of light. When the instrument is standing still the image that you get is in the form of a line. If an alternating current is passed through the instrument the image broadens.

Jefferson E. Kershner: Do you measure the width of the line?

Frank Wenner: The width of the line is an indication of the amplitude of vibration. The motion being slower at the ends, it seems to stand out, as two lines. Of course, you can read it from a pointer, but in most of the work in which the vibration galvanometer has been used they use a reflecting system.

W. H. Pratt: I would ask how rapidly the sensitiveness of the instrument is reduced as you depart from the ideal conditions outlined?

Frank Wenner: It all depends on what you want to do with the instrument, as the sensitiveness can be controlled in design. If you want to construct an instrument which will not respond to the harmonics, and you are going to use it at a very definite frequency, you can afford to reduce the range in frequency, to, say, one-tenth of a per cent at which it will operate. Then it practically does not respond at all to any of the harmonics. If, on the other hand, you want to use it at commercial frequencies, the instrument should be designed so that it has a very flat top sensitivity curve. The way this curve drops off has no connection at all with the maximum height of the curve. The sensitivity at the resonating frequency is independent of whether you make this curve steep or not.

W. H. Pratt: This last point you mentioned, about the width of the curve not being dependent on the maximum point, can that be controlled by the iron in the circuit. For instance, your iron in the inductive circuit of the instrument, having some hystereses, would tend to broaden the range over which there was a resonant resistance. Does that have an appreciable effect?

Frank Wenner: No, I think not. The matter that affects the sharpness of this curve depends almost entirely on the mechanical constants of the instrument. It bears a little on the electrical constants of the circuit, but only slightly.

R. A. Gray: Is the instruments chiefly used as a deflection instrument or as a zero instrument?

Frank Wenner: It is used almost entirely as a zero instrument. It has been used to some extent as a deflection instrument and there is no reason why it cannot be so used. The deflections

are as nearly proportional to the e.m.f. as they are in other deflection instruments.

Albert F. Ganz: By deflection, do you mean the width of the reflected band of light? Is that what measures the vibration?

Frank Wenner: Yes, that reflection can be brought back on the transparent scale and read in divisions.

George F. Sever: Up to what specific point can that band be used in connection with the sensitiveness of the reading and the accuracy of the reading of the instrument?

Frank Wenner: I have used it up to a few centimeters, but then only in determining some of the constants of the instrument, and was not, at that time, concerned with it as a deflection instrument. Ordinarily, the deflection is very small when it is used in the usual way.

N. Monroe Hopkins: Is the band quite distinct on the right and left edge respectively?

Frank Wenner: It is very distinct. When the band spreads out to considerable width it has this effect; it is very sharp on the extreme edges, and corresponding to the width of the filament of the lamp, or other source of illumination, it is comparatively bright, and from that it gradually shades off until you have nothing in the center.

John D. Ball: If the deflection is only a few centimeters is there not a correction for the width of the beam—the beam in zero position?

Frank Wenner: The source of the light that we ordinarily use is a filament from a lamp and focus it as sharply as possible. When you come to a very small deflection you might not be able to read it very definitely, and it would be necessary to read it not from the extreme edge, but from what corresponds to the center of the filament on each side of the image.

M. G. Lloyd: When you have the frequency adjusted to correspond with the natural frequency of the instrument, what relation is there between the deflection and current?

Frank Wenner: It is directly proportional either to the current or the voltage.

DISCUSSION ON "THE WIRING OF LARGE BUILDINGS FOR TELEPHONE SERVICE." (RHODES), BOSTON, MASS., JUNE 27, 1912. (SEE PROCEEDINGS FOR JULY 1912).

(*Subject to final revision for the Transactions.*)

Edwin M. Surprise: I noted in reading Mr. Rhodes' paper, that in New York City, at least, and probably in other places where very large and tall office buildings are under consideration, the scheme of attenuation is employed; that is, a large cable is brought in at the basement and branches taken off from that cable at necessary intervals. In our New England territory we have leaned a good deal toward the extension of small risers, one, two, or more, as may be required, to each floor, with the idea that it would result in economy, not only on account of the first cost of extending the cables, but also by reason of flexibility.

I am very much interested to get Mr. Rhodes' opinion regarding one method as against the other, of the advantages, if there are any, of small risers, and the exact point, if it is possible to give it, where perhaps small risers would prove best and where the large riser would not.

George K. Manson: Mr. Surprise referred to the question of comparative costs, or comparative conditions when the attenuation system proves economical as compared with the small riser system, and to supplement Mr. Surprise's remarks, before Mr. Rhodes gives us that information, it may be proper to say a little something about the building conditions in Boston that have led to the very general adoption of the small riser system in preference to the attenuation system.

Mr. Rhodes stated, I think, that twelve years ago there were very few buildings in New York City which were over twelve stories in height, and, to-day, I believe, he said there were 1500 or more. I believe somewhere in his paper, in reference, perhaps to the Hudson Terminal Buildings, he has spoken of a floor space of nearly 2,000,000 sq. ft. Now, we have in Boston, we think, a fairly large city, especially if we are allowed to take in the suburbs which properly belong to it. In Boston today I think I am not mistaken in saying that there is only one building which is over twelve stories in height, and that was built before the present building laws were in existence. If there is more than that, they also were built before the present building ordinance. As to the area, I presume it is very doubtful if there are half a dozen buildings in Boston that have, we will say, over ten per cent of the total rentable floor space referred to in Mr. Rhodes' paper in connection with the Hudson Terminal buildings.

The building law in Boston, briefly, is that no building in the city shall exceed 125 feet from the average sidewalk height to the roof line. If the width of the abutting street is so narrow that two and one-half times the width of the abutting street is less than 125 feet, then the building must be correspondingly less in height, and must not exceed two and a half times the width of

the abutting street, and is not to exceed 125 feet as a maximum, and in some parts of Boston there are special ordinances that restrict the height to even less than that.

You will see, therefore, that our problem of providing wiring for office buildings is a little different from that in New York and other cities where the development in terms of lines and perhaps subscribers may be no greater than the development in many of our medium-sized New England cities. It is by reason of that fact that in office building wiring we have found it is expedient, to a very large extent, to use the single riser system, perhaps one cable feeding a single floor, a 30-pair, or a 60-cable, or, perhaps, initially, one cable feeding two floors, and later to be tapped in such a manner as to supply a cable for each individual floor. I cannot quote figures at this moment, and possibly we could not back up our position, but I think under these conditions the single riser cable has proved economical; at least it is very convenient to install, and leads to very efficient results in the use of the main cables and in the use of the office cables. I trust Mr. Surprise will pardon me for enlarging on his question to that extent.

There is one other point that I will mention, and that is the vast reduction of the fire hazard that has been brought about by the modern methods of wiring buildings as compared with the older methods.

F. L. Rhodes: I think that Mr. Manson has, in supplementing what Mr. Surprise said, very well pointed out the wide range of conditions to be met in work of this kind. In building wiring, the reason why it is not the best practise to run separate cables to separate floors is principally a matter of economy, both as regards the cable itself and the space occupied. For a given number of pairs of wires, the most economical cable is secured by placing these all in one sheath. This is true, not only as regards the cost of the cable itself, but also true as regards the space occupied. One cable of 600 pairs occupies less section, and has less cost per pair than 10 cables of 60 pairs each, and these conditions of economy, both of cost and space, are intensified in the case of tall buildings as compared with the conditions that prevail in the case of buildings of comparatively few stories.

DISCUSSION ON "MEASUREMENTS OF VOLTAGE AND CURRENT OVER A LONG ARTIFICIAL POWER-TRANSMISSION LINE AT 25 AND 60 CYCLES PER SECOND" (KENNELLY AND LIEBERKNECHT), BOSTON, MASS., JUNE 25, 1912. (SEE PROCEEDINGS FOR JUNE, 1912.)

(Subject to final revision for the Transactions).

Charles P. Steinmetz: I have practically nothing to add, because the paper is so complete and the experimental investigations given check so closely with what we should expect theoretically, that the paper can be considered as one of those contributions which prove that our electrical engineering theory really is correct, that where, in practise, lines—whether artificial lines, lumpy lines, or distributed lines, are traversed by current, we find this current to be the same character as calculated by theory. A number of parabolic curves, as in Fig. 15, are given. Such curves have been advocated, based on theoretical assumption, but here you see they are reproduced from actual experience in a transmission line, showing that, at least in electrical engineering, theory and practise are identical.

John Price Jackson: I have not had a chance, I regret to say, to digest the paper; but I want to suggest, as Dr. Steinmetz just did, that, as far as I have observed, men who are willing to develop principles and methods in a simple, clear manner, which is readily understandable, are apt to do much to advance the science they are engaged in—possibly more so than those who leave their deductions in a complex condition. Professor Kennelly has the habit of lucid and simple expression, and I believe that his paper contains many suggestions, clearly stated, which will be of use to the college investigators, and investigators in other fields.

I would like to make a suggestion with reference to the printing of engineering data. The papers by Messrs. Harding, Peek, Whitehead, Ryan and others are making electrical engineering history. It seems to me that we could keep the original observations and computations of the investigators on file, possibly in duplicate, in the Institute library, when it is impossible to publish them in the TRANSACTIONS. They would then be available in future years, and might prove of great service to those who may wish to investigate the data in connection with the published papers, or those who may wish to undertake investigations bearing upon similar subjects. In fine, I hope that the board of Directors may see to it that all relevant original data that any author may wish to submit, in connection with those which are published in the TRANSACTIONS, are carefully bound, catalogued, and preserved in the Institute library in such a manner that they will be readily available to the membership for reference.

Charles F. Scott: Dr. Kennelly's paper is admirable in presenting in a clear, feasible way phenomena which, expressed in formulas, are pretty hard for the student to understand and interpret. The paper has been referred to by Dr. Steinmetz as one which proves or shows that our theories are correct. From another and more important standpoint, on the educational side,

this is an admirable means of showing what these formulas and theories really are and what they really mean.

From the educational standpoint, I would like to ask Dr. Kennelly to explain the manner of using apparatus of this kind. Two or three students may make an extended investigation extending over weeks or months. That is very good, but in what ways can an apparatus of this kind be most usefully employed with a large class, or a large number of students who cannot make a long series of measurements themselves?

John B. Taylor: I ask Dr. Kennelly in summing up to say a word about the choice of constants on this line, and whether he had any particular system in mind in laying it out. It seems to be a compromise between a telephone line and a power transmission line. I am interested to know if he expected to get anything for practical application, or whether his object was to construct something which would be useful for academic purposes.

A. E. Kennelly: In regard to the last inquiry, we took the constants of an actual long transmission line and tried to duplicate them in coils and condensers. We had to do a good deal of experimenting, to accomplish that, but the results represent a practical transmission line, although not a transmission line suitable for such great lengths as 650 miles. This experimental transmission line is intended to have a maximum length of 1500 miles.

In regard to Professor Scott's inquiry, it is true, as he says, that extended work upon such an apparatus can only be done carefully by a few men, but in regard to the use of such an apparatus more generally by a larger class, it is readily possible to put sections each of three men upon such apparatus for a single afternoon. Perhaps forty men could be put upon the apparatus in the course of twelve afternoons, and in that way a class might get practical information, by careful measurements with static voltmeters and closely calibrated ammeters, of the distribution of pressure and current along such a line.

One of the peculiar effects which is very significant and very interesting to the student who encounters it for the first time, is that when you free and then ground the distant end of a long line, you get more current when the line is free than when it is grounded, and that comes as a shock to the man who has been educated exclusively on Ohm's law.

In regard to the data of the paper, I might say that we had a great deal of difficulty in keeping down and eliminating the harmonics, and keeping both the frequency and voltage constant. If the voltage overleaps a little, or if the frequency overleaps a little, you get complex effects at the distant ends of a long line. It is necessary to keep these things constant.

DISCUSSION ON "DETERMINATION OF POWER EFFICIENCY OF ROTATING ELECTRICAL MACHINES" (OLIN), BOSTON, JUNE 28, 1912. (SEE PROCEEDINGS FOR JULY, 1912.)

(Subject to final revision for the Transactions.)

C. M. Green: I have had quite a little experience and difficulty in making efficiency tests on old arc machines—particularly the Brush arc generator. The input and output method, to the best of my knowledge, is the only method by which the efficiency of these machines can be determined, due to the fact of the large influence which the current in the armature has, at ordinary loads, on the eddy currents in the pole shoes and core loss. Furthermore, the field excitation on the Brush, etc., machines with no current in the armature, and rated volts, runs about 25 per cent of that with normal current and rated volts in the armature, so that you may see that the effect of the armature current upon the field windings is very abnormal. There is absolutely no question about the difficulty of making input and output efficiency tests. It is extremely difficult to get results which will check day in and day out. There is a continual variation of at least 2 or 3 per cent in the efficiency.

B. G. Lamme: I have gone over this paper of Mr. Olin's and discussed the matter with him personally to some extent, and I gather that the object of his paper was not so much to bring out a definite method of determining efficiency, as to show that there is a possibility of getting better results by the summation of separate losses than by the input and output method, unless the latter is carried out under laboratory methods. He has made a pretty good case of it. I have gone into this matter pretty thoroughly myself, and have calculated the load losses of various machines, and it is a very complicated problem to calculate these losses with any great accuracy; too complicated to be practicable as a basis for an acceptance test. But such calculations indicate that there are certain relations of load losses in most machines to the other losses, so that by some form of correcting factor, which we will doubtless determine some day, we can add a correction to the known measurable losses and obtain a result which is more reliable than can be obtained with the input-output tests. I have seen some very accurate input-output tests made, and even in the case of the most accurate ones, I had no confidence in the first one made; I had to see a second test to verify the first, or possibly sometimes a third one to verify the other two. If they all agreed, then I considered either that they were all accurate, or that there were equal errors in each. If I knew beforehand, what the true losses were, then I might accept the first test; otherwise I would not. I believe that, in practise, any method is an approximation; but what we want is an approximation in which the principal items can be computed directly from simple and reliable measurements. I believe as sufficient data is obtained a satisfactory method will be obtained for introducing a correcting factor for load losses, which factor may be varied for different types of machines.

E. M. Olin: In regard to the difficulty of testing the machine of which Mr. Green has spoken by the input-output method, my recollection is that it does not have any efficiency anyway, and any method will do as well as another. The point I make in this paper is that the input-output method is a laboratory method and as such is not adapted to an ordinary shop test.

DISCUSSION ON "APPLICATION OF ELECTRIC DRIVE TO PAPER CALENDERS" (MORSE) AND "ELECTRIC DRIVE FOR PAPER MACHINES" (HENDERSON) BOSTON, MASS., JUNE 28, 1912. (SEE PROCEEDINGS FOR JULY, 1912).

(Subject to final revision for the Transactions.)

W. B. Jackson: In connection with Mr. Morse's paper it occurs to me that a carefully devised electric clutch, or an electrically accelerated clutch, as is being used in single-motor printing press work today, might be used with advantage, since, if I understand the situation properly, in case the paper should break, arrangements could be made so that the clutch would be instantly opened and thereby almost all of the flywheel action to which the author has referred would be eliminated. In addition to having this advantage, the acceleration from the lower speed to the higher speed could be made I think probably with a little more exactness and a little more uniformity; and also the matter of the control can be worked on to the switchboards so that the control of the clutch and the control of the motor are in effect co-related so as to be substantially one single control.

J. S. Henderson. That style of control it seems to me would be a good deal better on a heavy cardboard calender or a rubber calender or a linoleum calender. I have seen such a thing as that put into operation and have in fact helped to apply the motor to one of those things and I understand it works very well, but I think that for a pure paper mill drive, that this is a little bit of a refinement. I don't know whether it will work out commercially or not, but I don't think it will.

W. B. Jackson: I should be interested to have a few more reasons for its not working out commercially.

J. S. Henderson: My idea was really as to the commercial value. I think the idea is good, but on a paper calender it becomes rather expensive.

W. B. Jackson: Is the added expense the objection?

J. S. Henderson: Yes, it is merely commercial.

W. N. Motter: (communicated after adjournment): I was very much interested in Mr. Henderson's paper, especially that part dealing with the question of regulation. I experienced some trouble with the regulation of an electric drive in a paper mill recently and I think a brief description of the system of electric drive and the method of overcoming the trouble, will be of interest in connection with Mr. Henderson's paper.

In this plant, the paper mill jackshaft is driven by a separately excited motor. This motor is supplied with power from an interpole, variable voltage generator, the speed being varied by adjusting the voltage on this generator.

We experienced a great deal of trouble due to poor speed regulation. This was caused by several unfavorable conditions as follows:

1. The steam pressure would vary somewhat at different times.

2. The engine had rather poor regulation.

3. The rewinding machine was driven from the jackshaft.
4. The changing of conditions of the calenders.

In a plant where so many variable conditions are liable to occur, it will be seen readily that inherent regulation naturally would be poor.

In order to overcome this, we installed a system of automatic control, as shown in the diagram herewith. Here we have the engine driving a small exciter. And the interpole generator *A* in which we can vary the voltage on the armature from zero up to 300 volts. This generator drives the constant field, separately excited motor, obtaining a 10 to 1 speed variation on the jackshaft by armature control. From the jackshaft

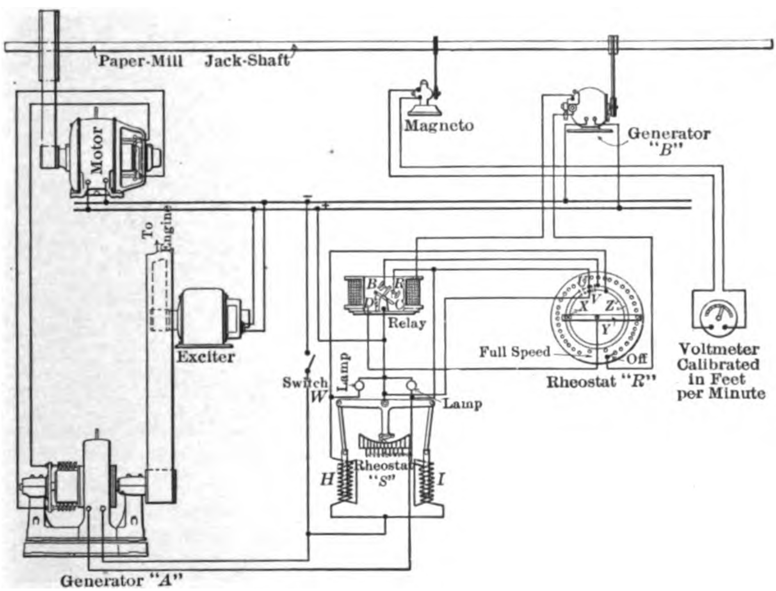


DIAGRAM FOR AUTOMATIC SPEED CONTROL

is belted a small generator *B* of 180-watt, 220-volt capacity. This generator is separately excited with constant excitation. The armature of this generator *B* is connected in series with the relay coil, which in turn is in series with the rheostat *R*.

The rheostat *R* has two rings *Z* insulated from the base, one of which is connected to one side of the solenoid, and the other is connected to the contact marked *B*. The lever arm *Y* has two brushes marked *X*, insulated from *Y*, bearing upon the rings *Z*. The method of operation is as follows:

The lever at *Y* being set on the off position, the brushes *X* come on the segments *U* and *V* for the off position. In order to start up the mill, we close the switch *W* and move the lever

arm *Y* on the rheostat *R* until the brushes *X* make contact with the rings *Z*. The current then flows from the positive exciter bus through the contact marked *B* on the relay, through the rings *Z*, which will energize the solenoid *H*. This, in turn, cuts out resistance in the rheostat S which is in series with the generator fields. This brings up the voltage on the generator, which in turn starts the motor.

As the jack shaft speeds up, the generator *B* generates a field in the relay which acts upon a magnet in opposition to the spring *D*. When this field becomes strong enough to make the pointer *R* come in contact with point *C*, the circuit will be closed through the solenoid *I*, which in turn controls the amount of resistance in the rheostat marked *S*. It will be noted that when *Y* is on the off position, the brushes *X* are on the plates *U* and *V*. This energizes the solenoid *I*, which insures a positive stop.

From this scheme it will be seen that any desired speed may be obtained and held constant by the amount of resistance in rheostat *R* which is in series with the generator marked *B*.

There is also a magneto belted to the jackshaft, which is connected to a voltmeter calibrated in feet per minute. This voltmeter gives the exact paper speed in feet per minute.

In actual operation, this automatic control has given exceptionally good results. We experienced some trouble at first due to the fact that the regulator contacts changed, also the relays acted rather sluggish, but these troubles have been overcome, and we are now able to hold the paper speed within 1% at any speed from 30 to 300 ft. per min. Of course when the rewinder, which requires about 7½ h.p., is thrown on or off, there will be a slight surge in the paper speed, but the automatic regulator will bring this back to its original speed within a very few seconds.

DISCUSSION ON "LOCALIZERS, SUPPRESSORS AND EXPERIMENTS" (CREIGHTON AND WHITTLESEY), AND "RELAY PROTECTIVE SYSTEMS" (ELDEN), BOSTON, MASS., JUNE 28, 1912. (SEE PROCEEDINGS FOR JULY, 1912.)

(*Subject to final revision for the Transactions.*)

D. W. Roper: Referring to Fig. 1 of Mr. Elden's paper where an outline of the Merz-Price system is shown, there is indicated a time limit overload relay in a generating station, in addition to the Merz-Price balance relay at both ends of the line. I do not quite understand the application of the overload relay at that place. As I understand the Merz-Price balance protection scheme, the object of it is to open up the switches on the two ends of a faulty section of cable so that this faulty section will be disconnected and allow the remaining sections to continue in operation. Later in the paper, it apparently indicates that the object of the overload relay is to take care of the trouble from a switch failure or short circuit on the station busbars, which are, as the diagram shows, obviously not protected by the Merz-Price balance protection system. If I am correct in my interpretation of these relay diagrams, I would like to learn how to set an overload relay so that it will not open in case of a cable breaking down, and have it open when the short-circuit occurs on the station bus-bars. If that scheme of discrimination can be carried out it certainly is very effective. The paper states that the operation of the Merz-Price system is a protection against faults in any part of a system, thereby permitting the operation of momentary and continuous overloads at the discretion of the operator. Apparently that wording, if I understand it correctly, refers to a system in which there is no synchronous apparatus, because synchronous apparatus would be thrown out of service by the heavy short circuits which that is apparently intended to cover. If that is the case I think it should be made more apparent because it is a very essential item in designing relay protection systems.

Harold Osborn: This system has so much to recommend it theoretically in that it suggests just the current which it is wished to have operate the relays and is independent of the low currents, that I judge its adoption in any given case is merely a matter or should be merely a matter of proper commercial value, the cost of the protection of the present systems, and the value of their protection. I suppose one of the principal objections to applying it to existing installations would be the necessity of changing current transformers, and the present practise, which I believe is general, of having single current transformers supply both protective relays and measuring instruments. I want to ask if it would not be perfectly practicable to use the present American transformers with this system and use those transformers still to supply the measuring instrument providing the voltages put in opposition were not the total voltage of the transformers but the voltage across certain impedances? Could not the balance system be applied to those impedances without changing the transformers? I have not read the paper

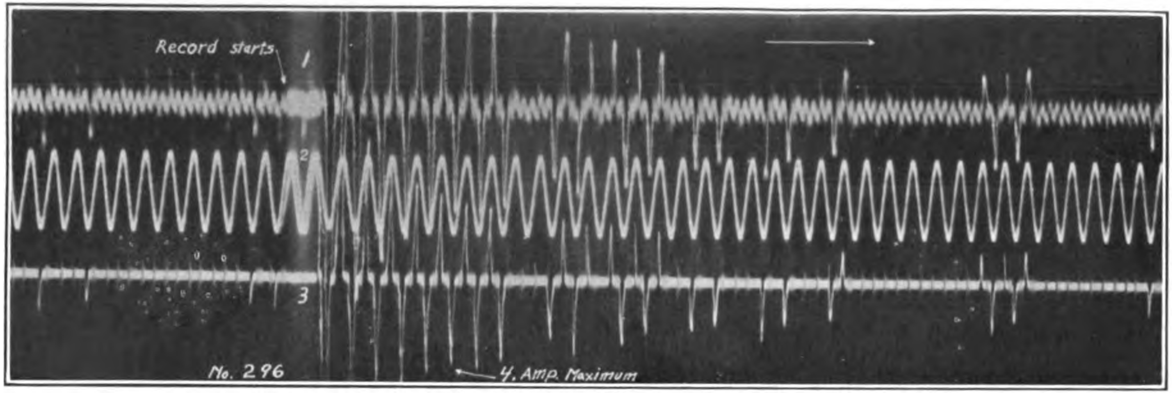
carefully enough to notice whether this system has been applied to busbars but it would seem to be particularly applicable to them.

L. C. Nicholson: In connection with Mr. Elden's paper it might be well to review the situation with reference to transmission lines. Whether or not a system of reverse current and overload relays operates successfully to isolate and cut off defective circuits does not appear to be the determining feature as affecting the continuous operation of synchronous receiving machinery. The limiting factor appears to be the speed of the oil switch opening the short circuit. The inherent electrical and mechanical lag of the best oil switches amounts to something more than one-half second. Consequently this is the least time in which a short circuit can be switched off, and unfortunately is too long a time for synchronous receiving machinery to operate successfully under the low voltage conditions usually accompanying a short circuit. For this reason we do not believe that a system of relays, no matter how perfect, can secure continuous delivery of power to synchronous machinery fed from transmission circuits connected in multiple.

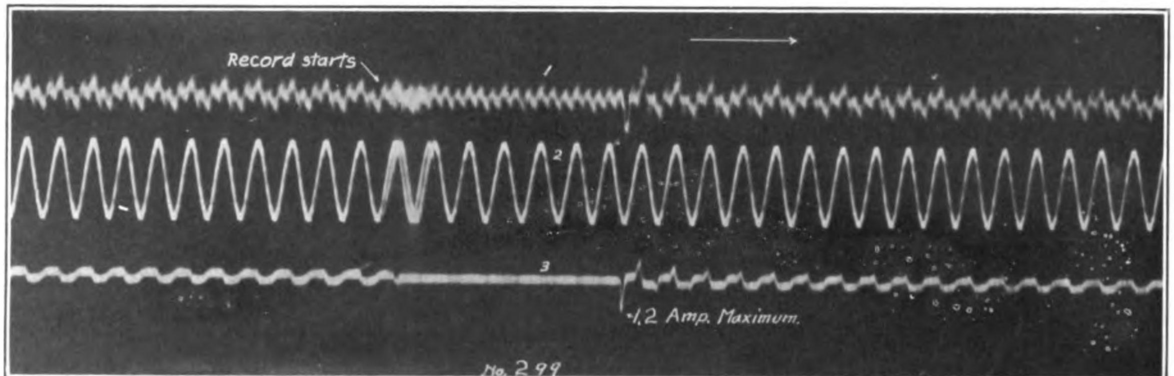
Professor Creighton's paper is very interesting. There is one point which I think should be made a little more clear. As I understand it, when applied to cable systems the action of the arc suppressor is to suppress the arc and keep it suppressed. In other words, it does not make a metallic ground and then remove it, but keeps the cable grounded until cut out of circuit. Otherwise I cannot see how the insulation which has once failed would again hold voltage.

E. E. F. Creighton: There is one question which Mr. Nicholson brought up. The arcing ground suppressor as described last year had an attachment for immediately opening the circuit. The switch short-circuits the arc to ground, and then opens. That device is applicable only to insulator trouble. When the arcing ground suppressor is applied to the cable system the grounding switch remains closed until the cable is disconnected, just as Mr. Nicholson suggested.

L. L. Elden: Referring to Mr. Roper's question, the reason for the use of the time limit relay on a system in which the Merz-Price control is used, is to enable the instantaneous disconnection of lines upon which faults may occur between conductors, or short circuits which may occur between station busbars, in order to prevent interrupting the service of the rest of the system. By viewing the diagram Fig. 1, it will be apparent that a short circuit on either of the substation buses will result in cutting out the station, without interfering with the rest of the system. The time limit relays on such lines are usually set at relatively long intervals, averaging 15 to 20 seconds, and at relatively high currents. Overloads on transmission lines within reasonable limits need not be feared with this system of protection, because when the load on a line has reached an amount which is dangerous, the



CHARGING AN ARRESTER 19 HOURS AFTER PREVIOUS CHARGE [CRICHTON]



CHARGING AN ARRESTER 13 MINUTES AFTER PREVIOUS CHARGE [CRICHTON]

1—Current in Generator Ground Wire
2—Potential Between Center Generator Lead and Ground
3—Current from Center Lead Through Arrester Tank

relay will operate to cut the line out of service, purely for reasons of overload. The same condition applies to time-limit relays between different ring systems, as in such cases the setting is instantaneous, thus permitting an immediate disconnection of two ring mains in case of a fault occurring on either, which action does not mean an interruption of service, but merely an interruption in a cross connection. The one point frequently lost sight of in considering this system of protection is that it operates only on fault currents.

In reply to Mr. Osborn, I would say that in general, American series transformers are not suitable for use with the balanced potential method of protection, although under certain conditions they may be used with the current balance method by substituting suitable relays for those now in use.

The use of this system in connection with high-tension aerial transmission lines, as referred to by Mr. Nicholson, appears to require a wide separation between the transmission line wires and the wires of the control system if open wiring is used, in order to prevent induced currents operating the relays when there is no occasion for their being so operated. The better plan appears to be to employ a three-conductor lead covered cable, suspended in a proper manner on the structure, which construction appears to be most satisfactory in operation.

It is a matter of record in one severe storm experienced, that as many as one hundred short circuits occurred on the overhead transmission lines of a large system without, however, disconnecting or interrupting the service from any single station. This simply means that the switches were restored immediately after opening, and were able to be maintained in operating position because the trouble was only momentary.

L. N. Crichton: (communicated after adjournment): The authors of this paper call attention, in Figs 11, 13 and 19, to the surges of current through the aluminum cells which are in circuit between the generator neutral and ground. The inference is that the surges are caused by an excessive potential at the neutral of the generator, but it is more probable that they are due to the characteristic of the aluminum cell and that there is little, if any, rise in potential. Fig. 19 is almost identical with a number of oscillograms which show the rush of current when a bank of 10,000-volt arresters is given its daily charge. The curve is not always so uniform. For example, the accompanying oscillogram, No. 296, shows the charging of an arrester 19 hours after the preceding charge. It is characteristic of these records that the current does not decrease as rapidly on one side of the zero line as on the other, probably because of the difference in the exposed area of the upper and lower surfaces of the aluminum cones. In oscillogram No. 299 is shown the charging of an arrester 13 minutes after a previous charge and it will be observed that even in such a short interval the hydroxide film on the cones has appreciably deteriorated. In the second case there is no spark gap in series

with the arrester so that some current is flowing, which finally becomes a leading current, but which contains a pronounced peak in phase with the peak of the voltage wave when the charge is started and before the film on the aluminum plates has had time to build up perfectly.

These tests were made by connecting the terminals of one arrester tank between the ground and one terminal of an 11,000-volt 3,600-kw. alternator which was carrying a load at the time. The current in the generator ground wire differs from the current in the arresters by the addition of a third harmonic charging current, of the system. The voltage wave across the arrester is shown and proves that there is no rise in potential on that phase at least. It is to be expected that a current wave having such a steep wave front would cause considerable rise in voltage across any inductance which might be in the circuit, and experience indicates that such is the case. To give two instances: a couple of banks of current transformers which are connected to a 45,000-volt circuit, spark across their high-tension terminals whenever the arresters are charged, either in their station or in a station three miles away. In the latter case, each transformer carried less than half the current which flows into the arresters. The potential necessary to cause this sparking is probably over 7,000 volts, but no harm has ever been caused by it. In the other instance, a magnetic vane type of ammeter which was used to measure directly the current passing through the arrester was damaged by puncturing between turns. It hardly seems possible that the current wave was sharp enough to induce such a voltage in a single turn of such a small coil, but no other explanation has been offered.

DISCUSSION ON "THE SQUIRREL CAGE INDUCTION GENERATOR" (HOBART AND KNOWLTON), "SINGLE-PHASE INDUCTION MOTORS" (BRANSON) AND "MOTOR STARTING CURRENTS AS AFFECTING LARGE TRANSMISSION SYSTEMS" (LINCOLN). BOSTON, MASS., JUNE 28, 1912. (SEE PROCEEDINGS FOR JUNE AND JULY, 1912).

(Subject to final revision for the Transactions.)

Lee Hagood: My remarks will be confined to the question of exciting current in connection with Mr. Hobart's and Mr. Knowlton's paper. As you will see from reading their paper, the matter of exciting currents bears very much on the question of air gaps. To some extent, the amount of exciting currents required may appear to be a very great objection to these machines. I wish to make the point that neither the design of the machine nor its application should be very much restricted on account of exciting current.

On most commercial systems, the exciting current is already large, due to the transformers and induction motors. The former require from 4 per cent to 8 per cent of the actual current, and the latter from 40 per cent to 80 per cent. Exciting current is wattless and 90 deg. out of phase with the energy current. Its magnitude depends upon matters of design. It may be supplied to a system by either synchronous motors or synchronous generators, and the amount supplied by any given machine to a system depends upon the direct current applied to the field of the unit in question. In the circuits involved in its transmission, it produces two important effects, one being a voltage difference, and the other energy losses. The losses are mostly copper losses.

The effect of exciting current on I^2R losses can be seen from the following equation:

$$\text{per cent losses} = \frac{\text{per cent losses at unity power factor}}{(\text{power factor})^2}$$

For example, if the losses in a transmission line were 8 per cent at unity power factor, they would be 16 per cent at 0.7 power factor.

The following equation represents approximately the voltage drop in a transmission, or feeder line

$$V = I_e R + I_w X \text{ when } I_w = I'_w - I_c/2$$

V is the voltage difference between a generating and receiving station: if the difference is a voltage drop, V must be taken as positive and if the difference is a rise V must be taken as negative; X and R represent the three-phase resistance and reactance between the points under consideration; I_e is the energy component of the current supplied the load; I'_w is the wattless component of the transmission line current at the receiving end; and I_c is the amount of wattless current required to charge the transmission line.

This formula is based on the assumption that the voltage drop,

due to the charging current, is equal to $(I_c/2)\,X$, and that we can disregard a very small quantity which should appear in the equation, namely $E_G\ (1 - \cos \alpha)$, where E_G is the generating voltage and α is the phase relation between the generating and receiving voltage.

Fig. 1 represents a synchronous generator and an induction generator in the same station supplying, in parallel, a non-inductive load. The induction generator will require about 30 per cent exciting current, or 800 wattless kv-a. This is substantially independent of load, and must be supplied by a synchronous machine. In the case illustrated in Fig. 1, neither the losses nor the voltage are of consequence, due to the smallness of the exciting current and distance of its transmission.

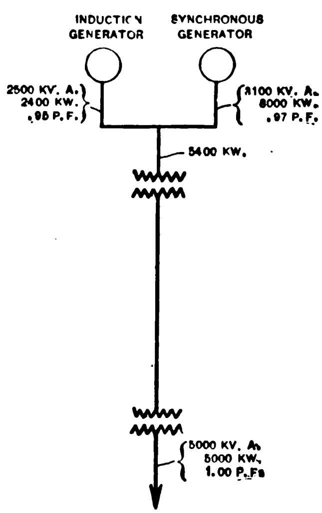


FIG. 1

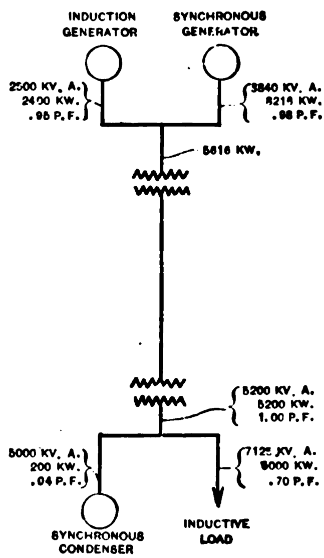


FIG. 2

Fig. 2 is similar to Fig. 1, except that the load is inductive and a synchronous condenser is applied, of sufficient capacity to carry the maximum wattless component of the load. The value of 70 per cent power factor used is one that often obtains in practise. The field of the synchronous condenser can be under automatic control by means of an automatic voltage regulator in such a manner that the power factor in the transmission line is corrected, and the voltage maintained constant across its bus-bars with a regulation of 2 per cent. Thus we can accomplish not only an excellent voltage regulation at a distribution center, but a saving in I^2R losses and the full use of the kilovolt-amperes of the apparatus involved. In the case given in Fig. 2, it is assumed that the transmission losses at unity power factor are

8 per cent. Without the synchronous condenser, the demand on the receiving and generating stations respectively would be 7125 and 7625 kv-a. whereas, with the synchronous condenser the demand is only 5200 and 5600 kv-a. To maintain this condition, a 60-cycle, 5000-kv-a. synchronous condenser would be suitable and would cost, with its switchboard and accessories, about $20,000. This additional investment is quite small, when we appreciate that the total investment in an installation for delivery of power to any point over a transmission line is based principally on kilovolt-amperes, and is in the magnitude, in a great many cases, of $150 per kv-a. In the above, we have reduced the kilovolt-ampere demand by about 2000 kv-a; the line losses have been reduced 8 per cent, and an excellent voltage regulation is accomplished. The losses in the synchronous condenser are about 4 per cent, but the better power factor in the generators has reduced their losses about 2.5 per cent: hence a net economy in losses of 6.5 per cent, or 375 kw. is obtained.

The smaller the constant voltage difference maintained between the generating and receiving station, the nearer constant will be the power factor. If we make this difference zero, the equivalent line power factor will be constant from no load to full load: for most transmission lines the equivalent power factor will be around unity, the exact value depending upon the relation $I_e/I_w = X/R$. The action of the synchronous condenser, controlled by its voltage regulator, is to hold constant voltage at the receiving station and in so doing it automatically carries all or part of the load's wattless kv-a., at all loads maintaining I'_w at such values as to meet the given voltage setting of the regulator.

I notice Mr. Lincoln referred to a system having a voltage regulation around 10 per cent. I have in mind two or three systems in which the regulation is 20 to 30 per cent. Induction regulators usually compensate for a voltage variation of about 20 per cent, and they cost, in general, for similar service, about half the price of a synchronous condenser for 60-cycle service; however, a synchronous condenser can not only take care of voltage regulation, but it corrects the power factor, as well, causing the consequent economies. Hence, there exists a wide application for its general use.

I believe that we will come to a very extensive application of synchronous condensers used for power factor correction and automatic voltage control. In view of this, I feel that but little restriction should be placed on exciting currents required by induction generators, induction motors and transformers. The design of all of these should lend themselves only to matters of cost, durability, etc.

Comfort A. Adams: In connection with the question of excitation in an alternating-current system, I wish to present the following point of view, which may be helpful to some. In any alternating-current system there are various magnetic

fields for all of which excitation must be provided; whether it be the field of an alternator, synchronous motor, induction motor, or the magnetic field surrounding the line wires. In most systems the only* or at least the principal fundamental source of excitation is the direct current supplied to the fields of the synchronous machines of the system. Any other magnetic fields, such as in induction motors, transformers or around the line wires, must be excited through the medium of reactive lagging currents which act as conveyers of the excitation from the source in the synchronous machines to the place of consumption. The greater the excitation demanded by these various secondary magnetic fields, the greater must be the excitation supplied by the direct-current field currents of the synchronous machines, in order to maintain the desired voltage, and the greater must be the lagging reactive currents required for conveying the excitation. Thus one advantage of supplying the excitation at or near the point of consumption is the obvious saving in the cost of transmitting it. But there is another sometimes greater advantage, namely the improvement in regulation and the ability to control the voltage at the receiving point by the adjustment of the excitation at that point. This point of view leads naturally to the consideration of a system in which the voltage is maintained at the same value at all points by means of properly distributed excitation.

Referring now to the paper of Messrs. Hobart and Knowlton, consider the question of core losses. We are sometimes tempted to pride ourselves upon the accuracy and definiteness of electrical engineering calculations, but in ordinary computations of the core losses of induction motors and induction generators, we must multiply the rational part of the formula by from two to four in order to make the results check with observations; that is, we acknowledge that the part of the core loss which we do not take account of rationally in our formulas is in some cases two or three times as large as the part rationally accounted for. The inevitable result is a very large probable error in any machine differing appreciably in design or construction from those previously tested.

One of the sources of this large discrepancy is clearly demonstrated by the oscillograms, Figs. 17 and 18; namely the pulsations of flux in the teeth at what may be called tooth frequency, and due to local variations of equivalent air gap permeance, caused by the slots and slot openings combined with a short air gap. But this local variation of gap permeance may also cause considerable tooth-frequency pulsations in the core back of the teeth. For example consider a rotor and stator with 20 and 21 slots per pole respectively. Starting with a rotor tooth, that is exactly opposite to a stator tooth at a particular instant,

*Electrostatic capacity either artificially inserted or natural to the system, such as the capacity of a transmission line, obviously contributes more or less exciting current.

there will be in this vicinity at the same instant a group of seven or eight rotor teeth each of which is nearly opposite to a stator tooth, and ten slots from our starting point there will be a similar group of seven or eight rotor teeth each of which is nearly opposite to a stator slot. The first group mentioned constitutes a region of high gap permeance and the second group a region of low gap permeance. But as the variation of gap permeance from point to point is gradual from maximum to minimum and back again, we shall have at any instant a complete wave or cycle of gap permeance variation for each pole. Had the number of slots per pole on rotor and stator differed by two instead of one, there would have been two complete waves for each pole; and so on.

A little consideration will show that these waves of gap permeance variation move along the gap periphery with a velocity corresponding exactly to tooth frequency; that is, the wave of variation moves one complete wave length while the rotor is moving one tooth pitch, or since the wave of gap permeance variation means a wave of gap flux density variation, the pulsation of flux density in the teeth will be at tooth frequency. But in the first case cited each half wave includes 10 teeth, and the resulting maximum of the flux wave must penetrate back into the core behind the teeth to a depth depending upon the length of the half-wave along the periphery, which is one-half of the pole pitch in the assumed case. The greater the difference between the number of rotor and of stator slots per pole the greater will be the number of gap permeance waves per pole and the less the depth to which the resulting flux pulsations penetrate back of the teeth.

It is obvious that in any case the resulting eddy currents will tend to damp out these pulsations, and to reduce the depths to which they penetrate, but that does not affect the validity of the above explanation.

It is also obvious that the more nearly the slots are closed and the longer is the air gap, the less will be the amplitude of the wave of reluctance variation.

There are thus in some cases tooth-frequency flux pulsations in a portion of the core back of the teeth as well as in the teeth themselves.

There is also the wave loss* due to the eddy currents induced in the tips of the stator teeth as the edges of the rotor teeth pass across them.

And finally there is the extra loss due to the breakdown of the insulation between the laminations. This last can be largely eliminated by more careful lamination, or by using less pressure when assembling the plates, or by both, although considerable pressure is desirable for mechanical reasons.

If these phenomena could be readily subjected to reasonably accurate analysis, there would be five separate core loss compu-

*See *Pole Face Losses*, A. I. E. E. TRANSACTIONS, xxviii, page 1133.

tations to make, excluding breakdown of insulation, in place of the one or two now employed. But unfortunately these phenomena are not as yet amenable to even roughly approximate quantitative analysis, as a little consideration will show. It is reasonable to expect, however, that some at least semi-rational method will be discovered for computing these losses separately. The speaker has been carrying on a series of experiments to this end and hopes later to present some useful results, although those thus far obtained are chiefly confirmatory of our previous conclusion, that the problem is a very difficult and complicated one.

Referring now to the question of neutralizing the pulsation of single-phase armature reaction by means of a squirrel cage damper, it is stated on page 1069 that "if the aggregate cross section provided by the face conductors of the squirrel cage equals the aggregate cross section of the stator conductors then the loss incurred in neutralizing the pulsations of the stator current, is about equal to the stator I^2R loss."

This damper loss has also been estimated at one half and one quarter of the above respectively by well known engineers.

All of these estimates are presumably based upon the assumption of perfect damping, that is that the leakage reactance between stator and damper windings is negligible, which is not the case.

The speaker has made careful computations of this loss with the following results. The method of computation will be set forth at another time. Suffice to say for the present that there are many factors entering into the computation, and that many approximations are necessary.

Assuming perfect damping as above and assuming the same current density in the damper as in the armature copper, the damper loss will about equal 70 per cent of the armature copper loss; with the same copper section in damper and armature, the damper loss will be somewhat less than 50 per cent of the stator copper loss. Practically the losses will be slightly less than indicated by these figures owing chiefly to the leakage reactance between armature and damper conductors, as the resistance is relatively a small factor.

E. F. W. Alexanderson: In connection with the remarks of Professor Adams I should like to mention the results of an investigation which I made in order to determine a practical equation for finding the high-frequency tooth losses in induction motors. It is a well-known fact to designers that the additional core loss, due to magnetic disturbances, is higher in induction motors than in synchronous machines. A number of induction motors were examined, using data available for machines of greatly varying losses and speeds, in order to find a law for the variation of the losses due to high-frequency magnetic disturbance in the teeth. It was anticipated that a formula could be based on the frequency of the magnetic disturbance or on the width of the teeth. However, on going over the material available, it was

found that in machines of the same peripheral speed the high-frequency loss was practically independent of the frequency, because a higher loss that might be expected from the higher frequencies is offset by the smaller penetration of the disturbance that necessarily accompanies a greater number of slots. As a result, it was concluded that the variations due to any other cause than the peripheral speed itself and the average flux density are smaller than the variation that occurs between machines of the same design, due to difference in the grade of iron or the mechanical treatment of the same. A formula was, therefore, evolved to determine the core loss due to high frequency in the teeth, which is based on peripheral speed and magnetic density of the gap only. The loss is proportional to the square of the speed, and the square of the density and the empirical constant is apparently the same from the largest and highest speed machines to the small or low-speed machines.

For induction motors of ordinary design with open slots and standard iron, the empirical formula for core loss due to tooth frequency is

$$\text{loss in kw.} = 0.13\ \frac{\text{diameter}}{\text{length}} \left(\frac{\text{rev. per min.} \times \text{megohms} \times \text{poles}}{10{,}000} \right)^2$$

The core loss in the original induction generator referred to in the Hobart paper may seem excessive, but it is in accord with the general law, as expressed by the above formula, and in order to reduce the tooth losses to such values as might be expected in synchronous machines, it was necessary to employ special measures. This condition will apply, in general, to induction generators, and is a circumstance that may make it difficult for such machines to compete with synchronous generators. However, this is a question that will answer itself, because the preference for one type of machine or the other can be expressed in dollars cost per kilowatt.

There is another consideration which I think is of importance, *i.e.*, the one referred to by Capt. Hagood, whether the power companies will favor a generator which needs lagging current for excitation. If it is agreed that the lagging component can be taken care of to advantage by synchronous condensers, a field is opened for other types of generators which have been practically forgotten, such as the Stanley double synchronous generator which makes it possible to operate a 25-cycle turbine set at 3000 rev. per min.

Lester McKenney (by letter): It seems to me that in making a rule as to the largest size motor to be allowed on a system, the rule should be based on the capacity of the system, or that part of the system supplying the section in which the motor is to be installed, rather than upon the capacity of the largest mill in that section, for the reason that a rule based on such a method would be more general in its application. As a result of the rule based upon the capacity of the largest mill, we see that if the

load on the system were made up of a great number of small mills, the largest motor would be of comparatively small size, and all out of proportion to the capacity of the system and its ability to furnish motor starting currents.

The number of motors of the maximum size allowable also deserves special consideration. The idea here is not so much to protect the consumer having a motor of the maximum size against voltage disturbances, when his motors are started, as to protect the balance of the consumers against such starting.

It is to be regretted that no charts were taken showing the voltage disturbances at the mills and at the centers of distribution, during the investigation, as such records would have given much valuable information on one of the principal points mentioned in the paper.

It hardly seems possible that poor voltage regulation would be tolerated, even on a large transmission system dealing in wholesale power, if it were not for the large expenditure required for its elimination. A considerable part of the cost of our equipment is due to the demand for good voltage regulation. It therefore seems desirable that we take advantage of everything to secure this result, even to limiting the sizes of motors permitted on our transmission systems, providing the result is not obtained by too great a sacrifice of other things.

Referring to the charts Figs. 1 and 2, it will be noted that in plant No. 3 the motors are overloaded, while in plant No. 8 they are underloaded; and that the ratio of the starting current to the running current is based on the actual load which obtained at the time. On this basis, the ratio was nearly the same in both plants. The starting currents are independent of the load on the motors, and it seems desirable, for the purpose of future comparisons, that the ratio of the starting currents to the running currents, be based on the rated full load current of the motors.

On this basis, the maximum starting current in plant No. 3 having squirrel-cage motors, would be 80 per cent of rated full load running current; while in plant No. 8 having wound rotor motors, the starting current is only 50 per cent of the rated full load running current. This seems a most reasonable basis of comparison, as it shows the relation of the starting currents to the capacity of the motors.

It seems to me, that the starting of squirrel-cage motors, with compensators, can be hurried to as great an extent as the starting of wound rotor motors, and just as great drafts of current caused thereby.

There is one other point in this comparison, which the paper does not bring out, and that is, the higher power factor of the starting currents of wound rotor motors which, for equal values, cause less voltage disturbance than the starting currents of squirrel-cage motors. The wound rotor motor is, therefore most to be desired where close voltage regulation is an important feature.

H. M. Hobart: Mr. Hagood first spoke of the synchronous condenser, and it would seem that if it should become customary to use a synchronous condenser to control the power factor of distribution systems the field for the induction generator would at the same time be slightly widened. I do not feel that the field for the induction generator in any case is going to be very extensive, but it certainly has several very important characteristics to which Mr. Knowlton and I have called attention in our paper. We have endeavored also to call attention to its faults and limitations so that both sides of the question could be understood.

There are certainly many cases where it would be of commercial advantage to have a considerable proportion of the plant consist of induction generators. Consequently from the standpoint of being in a position to realize these commercial advantages, it is to be hoped that Captain Hagood's views as to the rapid introduction of the synchronous condenser will be realized. It seems to me his argument is very sound, that they should be widely used. Professor Adams spoke of many interesting attributes of windings and the effect of employing either full pitch or fractional pitch. These were very interesting and it certainly is up to designers to keep this matter carefully in mind in such work. As to the loss in squirrel-cage windings it looks as if Professor Adams is correct, and that we have overestimated the I^2R loss needed in the squirrel-cage winding to effect a certain degree of compensation. On the other hand I believe we have underestimated the parasitic iron loss which will still remain on our hands due to incomplete compensation of the pulsations of magnetomotive force. I should personally be of the opinion that the net result would be substantially the same except that we ascribe it to I^2R loss where it is partly I^2R loss and partly hysteresis and eddy losses in the iron. It will be very interesting if Professor Adams will be willing to give the proof more thoroughly in his written contribution to the discussion. Mr. Alexanderson spoke of the greater losses which he considered to be inherent to the induction type of machine. I personally feel that any excess losses are nearly if not entirely attributable to the American plan of employing form-wound coils, and the consequent necessity for wide-open slots. Of course it is a great commercial advantage to have form-wound coils, but if you were to test European motors with nearly closed slots on both stator and rotor the losses would be found to be down to the values obtained on other types of electric machines. It is of more importance in induction machines to have closed slots because of the necessity of employing a very small air gap. It is also interesting to keep in mind the point that Mr. Alexanderson made that the recent revival of interest in induction generators carries our attention back to various less simple types of induction generators that have been brought out from time to time. And I am aware that Mr. Alexanderson has given a great deal of attention to some

of these types and finds that they possess qualities which will probably be of commercial value in the future.

E. Knowlton (by letter): On page 1066 mention is made of the method of ventilation for a high-speed induction generator. The statement regarding the lesser amount of cooling surface required with axial ventilation should not be construed as meaning that this feature can be entirely neglected. The amount of surface can be considerably reduced because of the lower temperature drop through the iron when the heat is transmitted along the plane of the laminations instead of transversely thereto, but one should not lose sight of the fact that the temperature drop at the surface should be taken into account as it is, even with axial ventilation, an appreciable part of the total drop. When the air passes through any machine in parallel paths the resistance of the paths should bear some relation to the heat to be absorbed by the air in the path. Because of other considerations it is usually difficult to accurately predetermine the paths but a careful test of a machine will generally suggest means of improvement. With some designs the inherent characteristics are such that the greater amount of air will be supplied to the hotter parts where it is needed, but in others special construction must be used to accomplish this result.

W. L. Waters (by letter): The paper of Messrs. Hobart and Knowlton is a very useful presentation of the status of the induction generator to date. As has been frequently pointed out in the past, the main field for this type of generator at the present time is in large city power systems operating synchronous machinery or in water-power systems consisting of a number of comparatively small isolated stations.

The authors describe the first really important installation of the induction generator on a large scale, and the tests made are both interesting and instructive. The suggestion that this type of generator is suitable for single-phase work is, I think, a somewhat radical one. It is essentially a generator for high power factor or leading power factor loads, while a single-phase load is usually a railway one of low power factor. The low efficiency of the single-phase generator is due almost entirely to the low output for given dimensions and weight, compared to the three-phase rating. The total losses are approximately the same for both single- and three-phase, so that the slight reduction in the eddy current loss in the damping circuit of the rotor claimed for the induction generator would have little effect upon the efficiency.

I fully expect that the induction generator will have an important future in power station work as soon as operating engineers realize fully its advantages, and the demand increases so that manufacturers can standardize them like synchronous units. I think Messrs. Hobart and Knowlton's paper will help greatly in again bringing this type of generator before the public and in familiarizing them with its characteristics.

DISCUSSION ON "SOME IMPRESSIONS OF THE ELECTRIC TRACTION SITUATION IN EUROPE" (EVELETH), SCHENECTADY, N. Y., MAY 17, 1912. (SEE PROCEEDINGS FOR MAY, 1912).

(*Subject to final revision for the Transactions.*)

B. G. Lamme: One important point brought out by Mr. Eveleth is the small drawbar pull in European locomotive practise. From all I have been able to learn from various publications and from engineers who have visited European roads, Mr. Eveleth's statement is entirely correct. The drawbar pulls, even in the case of their largest electric locomotives, are relatively small, compared with what we find in every-day practise in this country. For instance, in the case of one of the largest foreign electrifications now being undertaken, 30,000 lb. (13,600 kg.) is the largest drawbar pull contemplated, according to my information. This may be compared with some of the results obtained in this country. Take the Hoosac Tunnel electrification, for example, where the locomotives are able to develop 22,000 lb. (9980 kg.) continuously, and 72,000 lb. (32,658 kg.) during starting and acceleration. These locomotives will start and pull 2000-ton trains through the tunnel, using only a single locomotive. Some of the terminal electrifications in New York City will also compare well with the Hoosac Tunnel in tractive effort. Also, the Sarnia Tunnel locomotives, which handle through-service largely, have gone up to tractive efforts as high as 98,000 lb. (44,452 kg.) by actual measurement. These locomotives will develop tractive effort up to a point where they slip the wheels, even though the locomotives are relatively heavy and have all their weight on their drivers.

Considering electrifications in Europe, as a whole, with the exception of the Giovi electrification, they are not very extensive and, to a certain extent, much of the locomotive work is experimental, as Mr. Eveleth has brought out. All the European work combined may be said to be hardly comparable with some single installations in this country, such as the New York Central, the Pennsylvania, or the New Haven installations. I cannot give you offhand the total motor capacity of the New York Central, or the Pennsylvania installations, but in the case of the New Haven electrification, I can give some rough figures. In that system there is a total of 146,000 h.p. in 106 locomotives.

The Simplon Tunnel electrification has been very much advertised. It is an excellent piece of work, but when you consider it as a whole, it is comparable with some of the tunnel work which has been done in this country. For instance, the Sarnia Tunnel, with 3300 volts on the trolley, the same as the Simplon Tunnel, has a service which is probably equivalent to that of the Simplon. Then there is the Cascade Tunnel with 6600 volts on the trolley, against 3300 on the Simplon Tunnel. Also, there is the Hoosac Tunnel with 11,000 volts on the trolley, and yet we do not hear much said about that, compared with the way the Simplon Tunnel has been advertised. All

these tunnels which I have mentioned are roughly comparable with the Simplon Tunnel and, in some respects, their electrical problems were more difficult.

The engineering in the Simplon Tunnel electrification is very interesting in many respects. For instance, the later locomotive motors are made with two windings and four speeds, and the secondaries of the motors are of the cage type, so that the same winding can be used with the various primary windings and their combinations. These cage-wound secondaries are apparently very successful. In this case, however, they have a given definite service and the hauls are relatively short. I hardly think that type of motor, with a cage winding, would be very suitable for general railway work. It is adapted for one specified condition, but would hardly be suitable where no definite conditions or hauls are prescribed and adhered to.

Taking up some of the individual electrifications mentioned by Mr. Eveleth, the Midland Railways in England is referred to as not being very satisfactory. To a certain extent I think that is correct. However, part of the equipment there is of American make, and partly of European. In a report, published by one of the engineers of that road, was given a list of all the troubles which they had encountered during a period of about two years. The whole description is confined to troubles with the German-made equipment. In referring to the American-made equipment, the only statement was that this had given no trouble, and that such result was to be expected as the equipment had already been standardized in America.

Among the electrifications in France, the Midi was mentioned, and this was commented on as being experimental. As far as locomotives are concerned, this is an experimental electrification. They have bought five or six different types of locomotives with the intention of finding out which type suits them best, but the principal electrification at present is in motor cars, of which they have bought 30 equipments, of four 125-h.p. motors each, with the intention of putting them into regular service before the locomotive problem is decided. The important immediate service thus will be with motor cars, which is not experimental, and the extended service of the road, which is eventually to cover 250 miles, is to be carried out with electric locomotives. Of these locomotives, the construction of one, or possibly two, has been placed with the foreign representatives of American companies, and will probably be built along American lines, while the others will be built principally by German or Swiss companies, or by their French allied companies.

In Switzerland, the Loetschberg Tunnel electrification is the most interesting of the later ones, and here they have installed two or three different types of locomotives. According to reports, the Oerlikon locomotive has, so far, been the most successful one. This is a combined gear and side-rod type of locomotive. It has been inspected by a number of American engi-

neers, who report that it is apparently very successful. It is operated on 15 cycles, where vibration due to low frequency is more likely to appear, but there seems to be no vibration whatever in this locomotive, which to me is a rather unexpected result, for there does not appear to be any provision in the way of springs or cushions to take up vibration, as has been the practise in this country, in tests with 15 cycles on large capacity locomotives. This absence of vibration is possibly due to the fact that the motors run at relatively high peripheral speeds, and this, with the combination of gears and side rods, allows vibration to be damped out. A very slight movement at the periphery of a high-speed armature of a geared outfit may serve to take up a considerable amount of the vibration. In the Loetschberg installation, there was one German locomotive installed which had to be taken out for reconstruction. It was a side-rod type purely, and it was reported that it vibrated very badly and that the commutation was relatively poor. With the side rods only, the motor was necessarily of relatively low speed, and thus the tendency to damp out vibration by high speed of the motor was lost.

In Germany, the single-phase locomotive has been advocated almost exclusively. They have lately been encountering some trouble from vibration on the locomotives. In some cases this was pretty serious, but in general, was not as serious as it would be in this country if we attempted 15-cycle single-phase locomotives without means for taking up the vibration, for the foreign drawbar pulls are so much less, relatively, than are used in this country. If they attempted to pull anything like what we do here, in the way of accelerating tractive efforts, the vibrations of their apparatus would probably be excessive, or even prohibitive, in some cases, unless suitable cushioning means were provided for taking up this vibration. It is my opinion that eventually they will adopt some means for suppressing this vibration.

In some of the German locomotives, a single very low speed motor is used, of the same speed as the locomotive axles, to which it is connected by side rods. One reason for this low speed lies in the type of motor used by some of the companies, namely, the repulsion type or some of its modifications. Usually, where a repulsion motor is used, the motor can run above synchronous speed only to a comparatively slight degree without serious sparking. Consequently, normal operation is around synchronous speed or below. As fairly large capacity motors are used for this locomotive service, and as the armature voltage of such motors is always relatively low, they must have a comparatively large number of poles. This large number of poles, with the low frequency of 15 cycles, means a relatively low synchronous speed, or a speed not far from that of the driving axles, so that, if geared, a very low gear ratio would be required. In consequence, a relatively small number of very large motors is used, with direct connection to the drivers by means of side rods.

The a-c. series type of motor, however, is not subject to any particular disadvantage in running above synchronous speed, so that in general this type of motor is usually geared to the axle and, when operated on 15 cycles, usually runs very considerably above synchronism under normal conditions. The series type of motor, or some of its modifications, therefore, has a very considerable advantage for this class of service.

There is one thing they are doing in Germany which does not appeal to us in this country; that is, they are introducing too many fads in their apparatus. For instance, one of their latest fads is to regulate the speed of the motors by "rocking" or "shifting" the brushes on the commutator, and in this way they aim to save the weight and cost of the usual controller required with such apparatus. But it seems to me that in these schemes they are liable to run into various difficulties before they get through, and apparently they are finding some of them already.

Also, there has been some demand for induction regulators for regulating the speed of the motors. This was tried and abandoned in this country several years ago, for the induction regulator for this service, unless comparatively large and heavy for its capacity, is in reality more effective as a reactance, or a choke coil, than as a true induction regulator. The whole effort in Germany seems to be to get away from the controller, which, in our experience, is one of the least troublesome parts of the equipment when reasonably well designed. One German company has used a system of speed control by rocking the brushes over a limited range, combined with several voltage steps from the main transformer. The brushes are rocked to give a speed range corresponding to the voltage range between two transformer taps. The brushes are then rocked back and the voltage stepped to the next tap, and the operation repeated. While there are certain advantages in such arrangements, it seems to me that, as a whole, they are handicaps.

In this country we have found that we are limited in the capacity which we can get out of our locomotive equipments, by the permissible limiting speed conditions. If, for instance, we choose an armature peripheral speed of 7000 ft. (2134 m.) per minute, then we recognize that this speed must be considerably below what will be obtained at times, because we know that the limits we set are exceeded, not infrequently, even when contract guarantees set a positive limit to the speed at which the apparatus is to run. We are obliged, therefore, to allow a considerable margin over our guarantees, simply because, in practise, the guarantees are not adhered to strictly. In European practise, however, they do keep within the limits more strictly, and for that reason they can go to higher armature peripheral speeds than we do. Maximum armature peripheral speeds of 9000 ft. (2743 m.) per minute are apparently not uncommon in some European railway work, which is considerably higher than is

usual practise in this country. This point must be taken into account in comparing the relative capacities of European and American equipment, etc.

As brought out before, in Europe a small number of large motors seem to be preferred, on the single-phase locomotives. In this country, the tendency has been rather toward a large number of small motors for such work. For instance, in the more recent New Haven locomotives, in place of each of the four large motors, there are two smaller motors, each of nominally half capacity. The reason for this is partly in the electrical conditions, but is largely due to mechanical reasons. With individual motors of high power, if spur gears are used, two pinions are required, one at each end of the armature, and each of these pinions must line up exactly with the two gears on the driving axle. In order to obtain proper alignment of the gears and pinions, there should really be some adjustable arrangement between the gears, or there are likely to be undue gear stresses; but by splitting the large motor into two smaller ones, placed side by side, their pinions may mesh with one large gear, and no special alignment is required, and at the same time, a single gear is used instead of two. By this arrangement, a very considerable saving in weight is secured, principally in the mechanical parts, and the arrangement is mechanically simpler and better.

There is one further point which I might bring up—that is, in connection with the 3500-volt direct-current generator used in some of the English tests mentioned by Mr. Eveleth. I have had some experience with 1500-volt machines with a single commutator, and I want to say that I will never have any great liking for a 3500-volt constant potential machine with a single commutator. It may be all right for experimental purposes, but, in my mind, if you want 3500-volt direct-current, at least two machines in series should be used. Such a machine with a single commutator is a difficult and awkward one to build. I will give some figures showing wherein 3500 volts on a single commutator is objectionable from the design standpoint. Assuming, first, that 36 commutator bars per pole is as small a number as we would care to use on a 600-volt machine, then with 3500 volts approximately 210 commutator bars per pole, or between adjacent neutral points, would be required. Assuming the thickness of $\frac{3}{16}$ in. (4.7 mm.) per bar, plus its mica, then with 210 bars, approximately 40 in. (1 m.) would be required on the commutator between adjacent neutral points. With a commutator peripheral speed of 5000 ft. (1524 m.) per minute, 40 in. (1 m.) between neutral points would necessitate a frequency (revolutions per minute times the number of poles) of not more than 1500 alternations per minute. With a 4-pole machine, this would mean a maximum speed of 375 rev. per min., which is pretty low for ordinary capacity machines. Also, with a 4-pole machine, 40 in. (1 m.) between neutral points means a commutator about 50 in. (127 cm.) in diameter; that is, a max-

imum speed of 375 revolutions and a minimum commutator diameter of 50 in. (127 cm.) is the best that can be obtained in a 4-pole machine. With more poles, conditions would be correspondingly worse. In order to obtain higher revolutions per minute with 4 poles, for instance, either a higher commutator speed than 5000 ft. (1524 in.) per minute is required, or the commutator bars must be made correspondingly thinner. By making 2-pole machines instead of 4-pole, the revolutions per minute could be doubled and the commutator diameter could be cut to one-half. But a 2-pole generator of 500-kw. capacity, for instance, would be a freak. Therefore, I do not consider the use of such a high voltage very practicable on a single commutator, and two machines in series would be preferable. I am simply giving these data to show that certain experimental work under freak conditions should not be given any undue weight. If the rest of this 3500-volt English experimental equipment is in the same class with the generator, I would not consider the results obtained as being of any great practical value. However, the generator may be simply experimental, and the rest of the equipment may be along more reasonable lines.

E. F. W. Alexanderson: A year ago I had a chance to visit several of the European manufacturers, in Germany, Switzerland, France and England, and I wish to confirm the opinion expressed by Mr. Lamme that the work that has been done in electrification in this country is considerably ahead of the work in Europe. There may be reason for making this statement because I believe there is a popular impression that, particularly in single-phase work, the development in Europe is ahead of this country. So much has been written in the European press and so many descriptions and diagrams given of the locomotives that are contemplated or in course of construction, that one is surprised to find how much of this is only on paper or only in a state of experimental development.

As to the types of locomotives that are now being developed, it is interesting to see that the type of construction that is being favored is rapidly changing towards the types which are at present favored by American designers.

Mr. Lamme referred to the preference for repulsion motors as being responsible for the choice of locomotive types employing low-speed gearless motors. I believe, however, that the type of motor has had very little influence on the selection of type of locomotive, and that the ultimate development will be the combination of the locomotive type and the motor type, each of which is *per se* the most suitable. There are two manufacturers who have been for years advocating the use of the repulsion motor exclusively, one the compensated repulsion motor of one kind, and the other a repulsion motor with brush shift control. The repulsion motor is a slow-speed motor, and a very excellent motor, for that matter, when used in the right place, but it is interesting to see that the European manu-

facturers who have been advocating the repulsion motor as the principal form of locomotive motor are abandoning it. The Loetschberg locomotive originally built with repulsion motors has such proportions that it seems almost impossible that it could be used, and I understand that it is being abandoned. The same is the case with a locomotive built for the Midi Railway with repulsion motor of the other type. In looking over the machines of later design built by the various manufacturers, it was interesting to note they were all of the types which have been for some time favored by American designers; in other words, some form of series motor, with a commutating field as the normal running connection. The repulsion motor connection is very useful for starting purposes, and this form of starting is being adopted by some of the European manufacturers, whereas the method of using a resistance lead is used by other manufacturers. I do not want to advocate any one of these methods in preference to the other, although I might be suspected to favor one. I think it has been established that the resistance lead method, as well as the repulsion motor method for starting, is successful, but as for running connection at high speed there is nothing at present which is accepted as feasible except some form of series motor.

W. B. Potter: Mr. Eveleth's paper and Mr. Lamme's remarks indicate an activity among European engineers very creditable as to the development of the art, but perhaps open to question in some instances as to the economic results.

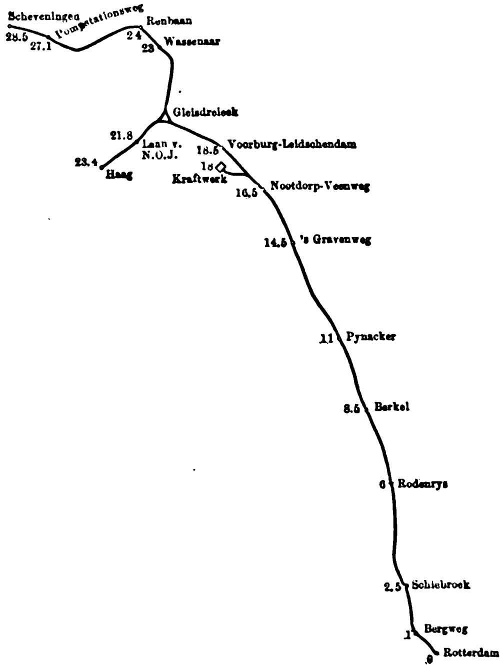
The conditions broadly affecting the choice of system for railways in this country may so far differ from those in some parts of Europe as to render misleading any direct comparison. The initial cost and cost of operation are items generally regarded in America as paramount to an arbitrary preference for any particular system, hence the natural result has been the development of what might be called local standards rather than attempt to subordinate the economics to one general standard.

Several references have been made to the differences in European and American practise as regards the development of the electric locomotive. The side-rod method of drive, which has been so generally used abroad, is well represented in this country by the powerful side-rod locomotives of the Pennsylvania Railroad. Mounting the motors in the locomotive frame has an advantage in raising the center of gravity of the spring supported motors and provides more space for the motor design. There is reasonable question, however, whether direct connection with side rods will be found as satisfactory as a combination of gears and side rods, the motor being geared to the jack shaft and the jack shaft connected to the driving wheels by parallel rods. This construction permits the use of lighter motors, eliminates the upward thrust of the armature bearings and reduces the number of crank centers that have to be maintained in alignment. The method of drive using both gears and side

rods appears to be receiving greater attention both in this country and abroad, and for motors carried by the locomotive framing it may reasonably become the preferred practise.

Differing from European practise in direct-current locomotives and a further development of the bipolar locomotive originally furnished the New York Central, is the new eight-motor locomotive with bipolar motors having all axles equipped and acting as drivers. With this construction the total weight has been reduced and the tractive power and motor capacity increased.

Mr. Eveleth mentioned briefly the self-propelled motor car as used abroad. More, perhaps, has been accomplished in this



MAP OF ROTTERDAM-HAGUE-SCHEVENINGEN RAILWAY.

country, considering the size of cars, speeds and distances operated. It is a type of equipment well adapted to fill in between main line service and the electric trolley car, and the more general use of self-propelled cars may reasonably be expected on the railroads of this country.

Eugen Eichel (by letter): Permit me to make a few statements regarding this paper, which shows that even a very good engineer can be greatly deceived by impressions gained on a short visit to a large foreign territory. An initial mistake in making an investigating trip is the omission of trying to get in

advance as many data as possible about the subject to be studied. The technical press is nowadays so instructive that main facts of great importance can be obtained with very little trouble by an earnest study of the articles already published. Thus it would have been very easy for Mr. Eveleth to avoid a number of bad errors, stated as impressions, if he had merely taken to hand a German electric journal such as *Electrische Kraftbetriebe und Bahnen*, not to mention an American publication such as the *Electric Railway Journal*. I shall not endeavor to point out all the mistakes contained in the paper, but will merely mention a few which show that Mr. Eveleth apparently neither studied the literature earnestly nor took great pains to obtain the correct data which he ought to have asked for from the proper sources during his stay in Europe. Take for instance the report about:

Holland. The Rotterdam-Hague-Scheveningen Railway has a very severe schedule, running 4-car trains at a maximum speed of 62 miles (100 km.) per hour, the motor cars weighing 51 tons, the trailers 31 tons each. The service does not call for an average stop of about 10 miles (16 km.) distance, but, on the contrary, of 2.75 km., amounting to about 1.72 miles. The map herewith shows the distances between the different stops in km. It is true that the maintenance costs are rather high. However, this is not to be counted against single-phase traction. The maintenance costs are rather high with *all* Dutch roads due to the local and climatic conditions. The track must be laid on a ground which is of the nature of a bog, thus requiring heavy ballasting and expensive maintenance, particularly so during the first few years. The overhead lines are exposed to the damp, salty, seaside atmosphere and must be very well insulated and protected against oxidation. The rolling stock is exposed to the sharp flying sea sand which intrudes in all crevices, causing, particularly, bearing troubles.

France. There are in operation in France, besides a few smaller systems of street railway character, a number of important single-phase interurban lines, for instance the Chemin de Fer du Sud de la France, a mountain railway operated with 10,000 volts, 25 cycles. A further system of importance is being built near Libourne, the " hinterland " of the famous wine exporting city Bordeaux. It is stated from a very reliable source that within a few years about 1500 km. (932 miles) of single-phase county railways are to be in operation in France. This is independent of the efforts of large trunk lines, such as the Chemin de Fer du Midi, which is experimenting with heavy trunk single-phase locomotives for difficult mountain service. The 2400-volt d-c. traction system at La Mure is still an exception under the French railways being built by the Thury concern. There are only four locomotives in operation and since July, 1903, the date of starting the system, a new traction system of this kind has not been placed in operation in France.

Trunk line pusher service and commuter systems of the steam trunk lines entering Paris have to labor under difficulties similar to those of the New York Central and Pennsylvania with their New York terminals, such as tunnels, low bridges, etc., and therefore show a natural inclination to prefer third-rail, low-potential, *i.e.*, direct-current, service.

Switzerland. The single-phase Seebach-Wettingen trunk line installation was started with the specific idea of giving the nearby Oerlikon works a trial opportunity to develop single-phase equipments. It was started in 1903 with a single-phase locomotive collecting single-phase current from a trolley wire under 15,000-volt potential, feeding a 15-cycle single-phase a-c.-d-c. motor-generator, the latter operating direct-current traction motors on Ward-Leonard control. This motor-generator system was soon abandoned and replaced by straight single-phase locomotives of various types and designs. The trial line was equipped with various kinds of overhead construction and further successful experiments were made with different schemes for overcoming the bad influence of single-phase traction in nearby telephone and telegraph lines. All experiments were very instructive and facilitated the development of practical single-phase trunk line equipment, the practical results being the locomotives built and an order for the Lötschberg line and the orders for 11 locomotives to be furnished for the electrification on the Räthische steam trunk lines with 10,000-volt, $16\frac{2}{3}$-cycle single-phase current on the trolley wire. The electrification of the famous Gotthard Tunnel line (the Swiss Hoosac Tunnel on a still larger scale) with its long approaches, is also being planned to be carried out with single-phase current, due to the good results obtained on the Seebach-Wettingen and other European lines operated with single-phase current. The reasons for the discontinuance of electric service on the Seebach-Wettingen line are more or less of local character.

Italy. The enthusiasm of the Italian engineers for their three-phase system is only warranted for such conditions as prevail on those local lines which are at present electrified, that is, where very low speed and the mountainous character of the line, with long down grades, allow making use of power regeneration to a relatively large extent. The double trolley and the low trolley potential, and the small number of running speeds of the engines, seem not to recommend three-phase traction for long extended trunk lines for high-speed passenger traffic. The Italian government engineers show great interest in the entire question of electrifying trunk lines and are keeping a watchful eye upon other European trunk line developments. They are particularly following the German development of single-phase trunk line electrification; they study, too, storage battery cars and gasoline-electric cars as means for maintaining regular passenger service upon suburban lines of light traffic which do not justify train operation.

Germany. It is very difficult to rectify in a short reply all the erroneous ideas expressed by Mr. Eveleth regarding German practise. He can be sure, however, that the German government railway engineers made a very thorough study of the *entire* question of trunk line electrification, including, particularly, operating expenses, before they decided on the choice of single-phase for main trunk line electrifications. The German government railways are the most important source of income of the government and the pennies are turned over two and three times before they are spent. The Altona-Hamburg-Ohlsdorf 6000-volt single-phase electrification is operating, technically and financially, very satisfactorily. The rolling stock comprises about 140 motor cars with two motors of 180 h.p. or three motors of 115 h.p. each. The German government is interested not only in heavy traction but also in satisfying the demand for light trains upon lines of light traffic and for commuter service. There are not only benzol-electric cars in operation on the Russian frontier, but such cars are distributed all over Germany to try their reliability under various climatic and operating conditions. So far the benzol-(a heavier oil than gasoline) electric motor cars have not proved as reliable as storage battery cars and it is a fact that there are in operation or on order a total of but 50 cars of the benzol-electric type. There are about three times as many storage battery cars in operation. The storage batteries have a capacity allowing the cars to be run about 60 miles (96 km.) with one charge, and a few cars are now being built with larger batteries allowing operation over about 100 miles (161 km.) on one charge.

The German and Swiss electrical manufacturers paid great attention to high-tension direct current. The Siemens-Schuckert works, especially, developed high-tension d-c. railway work very early. They started, for instance, the Cöln-Bonn 1000-volt d-c. railway in February, 1903, while the Berlin Elevated was started with 750-volt third rail in March, 1902. In 1906, 2000-volt freight locomotive service was started at Moselhütte. In fact, American high-tension d-c. practise might be traced to the influence of the German and Swiss practise in developing commutating-pole motors, the latter facilitating the designing of 1200-volt traction motors, generators and rotary converters.

Sweden. It seems to be worth while to call attention to the fact that the Swedish Riksgränsen Railway, which is continued over the Norwegian border down to the seaport Narvik, is a very important electrification of about 80 miles (129 km.) in length, requiring some of the heaviest locomotives so far built, their horse power output being 1220 h.p. for the passenger and limited trains and two 1220-h.p. short-coupled engines for the freight service.

I wish to repeat that all the above data can be confirmed by reference to reliable articles published in the German electrical journals by designing and operating engineers of the equipments

and plants in question. I would furthermore like to advise those engineers who going out on an investigation trip to Europe (1) to carefully study the information on the principal plants already accumulated in the columns of reliable technical journals, (2) to prepare abstracts which might be confirmed and extended during the trip and thus (3) to save considerable trouble and time in again collecting the data already at their disposal. The hurry of the trip and the foreign language very often cause misunderstandings.

The wrong impressions received are useless and their *bona fide* communication to important bodies such as the American Institute of Electrical Engineers ought to be avoided in an age which stands for the quick exchange of mental progress.

C. E. Eveleth: Mr. Lamme has brought out some interesting additions to this subject by describing more in detail some of the installations and locomotives. Such detailed information is always interesting and valuable and I wish to thank him for his contribution.

Mr. Eichel's discussion is interesting as typical of the viewpoint of a German technical editor. In general, he differs from my " impressions " in that he outlines what might be done and what it is planned to do in the future rather than confining himself to the evidence of things as they are.

A specific illustration of this difference of point of view is indicated by Mr. Eichel's comments on the Rotterdam-Hague-Scheveningen service. My statement of the service as not severe and represented by about a stop in ten miles (16 km.) is based on approximately the average distance between stops for both the local and express trains, there being three express trains to each local. He has given the distance between stations for the local trains only. The local trains make a schedule speed of approximately 21.5 miles per hour, *i.e.*, the 23.135 km.between Den Haag and Rotterdam in 40 minutes. This schedule can easily be maintained by an equipment never running over 35 miles (56.3 km.) per hour. As a matter of fact, although there are eight running taps in the control ranging from 116 to 360 volts, the drivers rarely go beyond the fourth position, and if I remember correctly are instructed not to go beyond the fifth except in emergencies. It may be that Mr. Eichel is right in believing that the trains could run 62 miles (100 km.) per hour, but they are never allowed to do so in actual service.

In this country we are inclined to be influenced more by the results which have actually been achieved than by theoretical possibilities.

DISCUSSION ON "FREQUENCY" (RUSHMORE), SCHENECTADY, N. Y., MAY 17, 1912. (SEE PROCEEDINGS FOR JUNE, 1912.)

Subject to final revision for the Transactions.

Samuel Sheldon: It is to be regretted that the author of this paper has seen fit to omit the unit costs which have been chosen for the ordinates of his curve-sheets and the unit capacities used for abscissas. Were these to be introduced, the value of the paper to the membership would be much enhanced. If commercial considerations compel their omission, information could at least be given as to whether suppressed zeros are to be associated with the axes of coordinates at their points of intersection. Such suppressed zeros are associated with the coordinates of the only figure whose units are designated.

John J. Frank: The comparative table of frequencies, and the table showing "frequencies used in some existing systems," should command attention. Speaking as a designing engineer of transformers, in my opinion the adherence to the latter table by operating companies would greatly benefit, not only the manufacturers, but the purchasers and users of transformers as well.

Frequency shows its effect on the design and operation of transformers in several ways; the amounts of material, cost, heating, losses, exciting current and mechanical forces vary with the frequency.

It has been shown that the loss in silicon steel now generally used in transformers is about 2.7 times as great for 60 cycles as for 25 cycles at normal densities. It is obvious that a transformer for 60-cycle operation designed at the most efficient density and the corresponding watts loss per pound will not operate as a 25-cycle transformer at the same watts per pound, as the exciting current resulting from the higher density will be prohibitive. With the same flux density and the same turns, the cross-section of the core for a 25-cycle design would be 2.4 times that required for a 60-cycle design, and the relative weights of the core somewhat greater. In commercial designs no such difference in core materials would be followed, as a 25-cycle design would operate at a higher density than a 60-cycle design, and the ratio of the copper to core loss would be greater for the 25-cycle than for the 60-cycle design.

In commercial designs it is necessary, in order to reduce the cost, to have no more material than is necessary. A small core gives large watts per pound with correspondingly high exciting current. A large core gives increased material and a more expensive design.

By comparison of the 25-cycle and 60-cycle commercial designs we find that the efficiency of the 25-cycle designs is about 0.8 to 0.2 of 1 per cent less than the 60-cycle design, while the cost is 20 to 50 per cent greater. No absolute comparison can be made between the relative cost and efficiency, as small changes in efficiency may in the use of standard parts

give large differences in cost. Frequency plays an important part in the operation of transformers. Operating a 25-cycle transformer on a 60-cycle circuit decreases the flux density and the core loss. Operating a 60-cycle transformer on a 25-cycle circuit increases the density and core loss, and in general gives a prohibitive exciting current. Frequency enters into the mechanical forces to which a transformer may be subjected, as the reactance increases with the frequency, and while the mechanical force varies directly as the square of the current, a 25-cycle transformer operating on a 60-cycle circuit would be subjected to about $\frac{1}{2}$ the mechanical strains on short-circuit. The limit of reactance in a transformer is about 8 per cent at 60 cycles and somewhat higher at 25 cycles.

B. G. Lamme: The subject of frequency seems to be a wide open one. In the beginning of this paper, attention is called to the general use of two standard frequencies. When I first started in the electrical business some 23 years ago, we had practically one frequency, namely 133 or 125 cycles per second, which we called the 16,000 or 15,000 alternation system. In those days all frequencies were given in alternations per minute, such as 16,000, and usually the frequencies were preferred in even thousands. The principal reason for the high frequency of that time was on account of the design of transformers, which were always of small capacity, for individual house lighting, and it was thought that smaller and cheaper house transformers could be built at 15,000 to 16,000 alternations than was practicable at lower frequencies.

About 1890 the question was actively taken up, of bringing into use a lower frequency, and a great deal of study was expended on the determination of a more suitable frequency. One argument in favor of a lower frequency was that it was more suitable for arc lighting, while the principal argument brought against it was that it was much less suitable for the transformers used with the incandescent lighting. In those days the induction motor was commercially unknown, and there were no synchronous converters nor synchronous motors to be considered in deciding this problem, and therefore the conditions required in arc and incandescent lighting had an almost exclusive influence in controlling the decision. It was considered that, in making such a change, it would be advisable to go to the extreme; that is, about half the then-existing frequencies, so that finally it was concluded that 8000 to 7500 alternations per minute would be as far as it would be practicable to go. A frequency of 7200 alternations per minute, or our present 60 cycles, was finally chosen, because it was the number of alternations which admitted of a nice choice of speeds for the generators. For example, with four poles, an 1800-revolution machine was obtained; six poles, 1200 revolutions; and eight poles, 900 revolutions would be obtained. These were all considered fine speeds in those days.

About 1892 the question came up, from time to time, of a still lower frequency. The first important case of this, with which I am familiar, was in connection with the first large Niagara Falls power plant. The Commission which was considering this plant was not satisfied with any of the high-frequencey propositions. Professor Forbes, who was electrical engineer of the Commission, was favorable to a very low frequency, and he proposed 2000 alternations per minute, or $16\frac{2}{3}$ cycles per second. One prominent argument which he made was that, with this low frequency, there was a probability of the use of commutating type alternating-current motors. In considering the use of a very low frequency, the company with which I am connected was favorable to 4000 alternations per minute, or $33\frac{1}{3}$ cycles. About that time we were working on our first rotary converters and we had built one 4-pole machine which operated at 1000 rev. per min., thus giving 4000 alternations, and we thought it was a pretty satisfactory machine, and we decided that 4000 alternations was a very suitable frequency for rotary converters. The speed of the proposed Niagara machines of 5000 h.p. was to be 250 rev. per min. We therefore figured originally on a 16-pole machine giving 4000 alternations, while Professor Forbes figured on an 8-pole machine giving 2000 alternations per minute. Finally, as we could not get together on either of these frequencies, we compromised on a 12-pole machine giving 3000 alternations per minute, or 25 cycles per second. This was the first large installation of this sort, and I believe that this is the real origin of the present 25-cycle system. It was a pretty good compromise, but possibly, in some ways, the choice of a little higher frequency would have been better, such as 30 cycles instead of 25, in view of the fact that 60 cycles has become one of the two accepted standard frequencies. With 60 and 30 as standards, we would then have a 2 : 1 ratio of our standard frequencies, which would have some very considerable advantages, especially in frequency changing.

That these two frequencies were not generally accepted as standard, is instanced by the fact that we have had in use in this country 66, 60, 50, 40, 33, 30, and 25 cycles, and quite a number of these were brought out after the selection of the 60 and 25 cycles.

In Europe, where there had been a still greater variety of frequencies, they did not adopt any standard frequencies until somewhat later than in this country, and by that time, 25 cycles had made considerable headway, so that they finally chose 50 and 25 cycles as their two standards, thus obtaining the 2 : 1 ratio. In this point they are somewhat better off than we are.

For a good many years, 25 cycles appeared to have great advantages in certain lines of work, such as in the transmission of power over long distances, and in conversion from alternating

to direct current. Where synchronous converters formed a considerable proportion of the load, 25-cycle systems were used almost entirely. Therefore, almost all the large railway plants adopted 25 cycles. However, where there was but very little conversion of alternating to direct current, 60 cycles has been most generally adopted.

Where 60 cycles was adopted, and any considerable demand for direct-current service came up, this frequency proved to be at considerable of a disadvantage, from the fact that, in earlier times, motor-generators had to be used. In attempting to overcome this difficulty, the 60-cycle synchronous converter was developed, but for a number of years it was considered to be a rather poor machine, and there were, in some cases, good reasons for this reputation. The limitations of design in those days did not allow what we now consider to be a very good machine. For example, in a synchronous converter, the distance between any two adjacent neutral points on the commutator. multiplied by the alternations per minute, gives the peripheral speed of the commutator. In a 60-cycle machine, that is, 7200 alternations per minute, with 6 in., or ½ ft. (152 mm.), between neutral points on the commutator, we would obtain a peripheral speed of 3600 ft. (1097 m.) per minute which, in those early days, was considered excessively high speed. It was therefore not considered practicable to make a 60-cycle synchronous converter without either using commutator speeds which were beyond the then-accepted good practice, or using distances between adjacent neutral points which were too small for good practice. Assuming we did use a little as 6 in (152 mm.) between adjacent neutral points on the commutator, then we would have difficulty in obtaining enough commutator bars for 600 volts. With a $\frac{3}{16}$-in. (4.8-mm.) thickness of commutator bar, for example, only 32 bars could be used between adjacent neutral points, which, in general, was considered unduly small for 600-volt railway service. It is obvious, therefore, that in whichever direction we turned, we were up against practical limitations in making such machines for relatively high voltages. I remember a conversation I had with Dr. Steinmetz about 14 years ago, in which we talked about 60-cycle synchronous converters. I took the stand that 600-volt machines were not very promising, as they are limited on account of mechanical conditions. He took the stand that 125-volt, 60-cycle machines were not very promising on account of certain electrical reasons. When we got through, only the 250-volt, 60-cycle synchronous converter had any standing.

As we obtained more experience with 60-cycle synchronous converter constructions, the peripheral speed of the commutator was increased, thus obtaining slightly more space between neutral points, and we finally managed to get from 36 to 40 bars per pole, which was fairly satisfactory, but required about 4500 ft. (1372 m.) peripheral speed at the commutator. We have

more recently become bolder and have raised the speed to 5000 ft. (1524 m.) or thereabout, and have thus been able to get in more commutator bars per pole. The construction of such machines is permissible, principally on account of improvements in mechanical construction. With such improvements the 60-cycle synchronous converter is taking a new hold, and it is probable that the 60-cycle field will be greatly extended on account of the greater perfection of the 60-cycle synchronous converter. In fact, 60-cycle synchronous converters are coming into quite extensive use in some fairly heavy railway propositions at the present time.

One condition which, in those early days, disturbed us very much in connection with 60-cycle synchronous converters, was that almost all of the generating plants were operated by reciprocating engines, and in some instances the generating units in the power plant would not operate satisfactorily in parallel with each other, and yet we were expected to operate synchronous converters successfully from such plants. Of course we had trouble. In those days we did not have the field-pole damper developed as it is now, although we had it in a crude form. In consequence of the bad generating conditions and the imperfect dampers, or absence of dampers, hunting of synchronous converters was not an unusual condition. Nowadays, the conditions are quite different, for we have many waterwheel and steam turbine driven generating plants, both of which methods of drive tend to give relatively good operating conditions. To illustrate the difficulties of those earlier times, I will cite one instance where we had a 60-cycle converter operating upon a system where the generating machines would not operate satisfactorily in parallel. The synchronous converter flashed badly at times, and apparently without sufficient reason, according to the claims of the operators. We investigated the case and found that they operated the converter from either of two generating stations, which did not operate in parallel, and occasionally they would throw the synchronous converter from one generating system to the other, regardless of whether or not the frequency was exactly the same. Sometimes the machine would flash and sometimes it would not, but when it did, they complained to us about the deficiency of our synchronous converter.

For general purposes, 60 cycles has apparently proved to be the more suitable frequency. With this frequency, a less limited range of induction motor speeds is obtained than with 25 cycles. With the lower frequency, a 2-pole motor would give a synchronous speed of 1500 revolutions, but 2-pole induction motors, as a rule, do not present any particular gain in cost or weight over 4-pole machines, and therefore 750 revolutions may be considered as high speed for 25 cycles, whereas 1800 revolutions can be used about as advantageously with 60 cycles. However, when it comes to very low speed work, such as certain kinds of

mill work, 60 cycles is almost prohibitive. For instance, where an induction motor is required to operate at 75 rev. per min., 60 cycles would require an 80-pole machine, which presents an almost impossible problem of design in an induction motor, if reasonable performance is to be obtained. However, with 25 cycles, such a machine may be entirely feasible.

From the preceding considerations, I think it may be safely said that the 60-cycle system is taking a new lease of life, and that a number of projects which formerly were only adapted for 25 cycles are now practicable at 60 cycles.

G. H. Stickney: In connection with the use of lamps on low-frequency circuits, much interest has been displayed with regard to the critical frequency below which flicker becomes evident or objectionable. The question has often been asked—" Is such and such a lamp satisfactory for operation on a 25-cycle circuit?" In general practise it has been assumed that 25 cycles is the minimum frequency acceptable for incandescent lamp operation. While this is approximately true, there are many factors which enter into the determination of the question under different conditions. In the first place, it is not an easy matter to define what constitutes an objectionable flicker. For the best class of lighting any perceptible flicker is, of course, objectionable. In low-intensity lighting on rough work (as in railway roundhouses) light having a very considerable flicker has been used to some extent without serious complaint.

Although the eye cannot distinguish a high-frequency flicker from steady light, the question has sometimes been raised as to whether, even under these circumstances, some eye-strain is not induced. As far as I have been able to learn, there is nothing to indicate that any such effect results. Even if a slight flicker can be observed, there appears to be no evidence of appreciable strain where the eyes are not applied constantly on close work. I have in mind a city in which the lighting circuit in the residence district was changed from 125 to 25 cycles several years ago, and apparently most of the consumers are entirely unconscious of any lack of steadiness in the light.

It is rather difficult to eliminate the influence of suggestion from the actual physical strain which would occur under a flickering light. This is evidenced by a case in which an individual used artificial light from a certain circuit daily for a period of some months without experiencing any difficulty from the light. When, however, his attention was called to the presence of the flicker, the light became immediately objectionable, causing eye-strain and headaches.

An important element entering into the perception of flicker is that of the intensity of the light: the greater the intensity the higher is the critical frequency. This flicker is often observed in the light source itself, when it is imperceptible in the illumination. In one city where arc lamps were operated just below the critical frequency, so that some objection was encountered, it

was found possible to minimize the flickering effect and overcome the objection by introducing large diffusing shades, thereby reducing the intrinsic brilliancy.

Another peculiarity of flicker effect is that the peripheral portions of the retina are more sensitive to this effect than the central portion. A light operating at about the critical frequency may appear steady when the observer looks directly at it, but appear to flicker when the gaze is directed at a nearby object, so that the lamp is seen, so to speak, out of the corner of the eye. Where there are moving objects crossings the line of vision, a multiple image effect is obtained even with frequencies far above the ordinary critical value, and this is, in some cases, a deciding factor in determining whether illumination is or is not satisfactory.

With some types of alternating-current lamps the intensity of light falls nearly to zero with the current during each cycle, due to the fact that the heat is conducted away rapidly. As would be expected, the greater the amplitude of intensity variation during the cycle, the higher will be the frequency at which the flicker becomes evident. In the incandescent lamp, for example, since the filament is enclosed in a vacuum, the heat is not rapidly conducted from the filament, so the instantaneous variation in intensity is less than in any other form of lamp in general use. On the other hand, there is considerable difference in this respect between the different sizes and voltages of incandescent lamps. For example, a filament of large diameter, such as would be used in an incandescent lamp of high wattage or low voltage, would, on account of its heat capacity, be subject to a minimum variation in temperature, and therefore in intensity of light, during a single cycle. It has often been observed that such lamps are less subject to flicker than the corresponding low wattage or high voltage lamps.

In comparing the carbon and tungsten filaments, it should be noted that, for a given diameter of filament, the tungsten is less subject to flicker than the carbon on account of its positive temperature coefficient of resistance. In comparing lamps of equal candle power, however, both on account of its higher efficiency and the lower resistance of the material, the tungsten filament is somewhat smaller in diameter than the corresponding carbon filament and the result is that, at the ordinary frequencies, the carbon filament is slightly less susceptible to flicker.

When 25-watt, 110-volt tungsten filament lamps are operated on 25 cycles, the flicker of the bare filament is visible. It is, therefore, desirable to conceal the filament by means of a translucent shade when this lamp is operated on 25 cycles.

In this discussion the question has been treated purely from a practical standpoint. Laboratory investigations of the phenomena of flicker have been made by Dr. H. E. Ives, Dr. A. E. Kennelly and others. Report of Dr. Ives' tests will

be found in the *Transactions* of the Illuminating Engineering Society for 1909, the paper entitled "Allowable Amplitudes of Frequency and Voltage Fluctuations in Incandescent Lamp Work." Reports of Dr. Kennelly's work will be found in a paper entitled "Frequencies of Flicker at which Variations in Illumination Vanish" by A. E. Kennelly and S. E. Whiting, in the *Proceedings* of the National Electric Light Association for 1907, and also a paper entitled "Flicker on Fixed and Rotating Targets," by Dr. A. E. Kennelly and others, in the *Transactions* of the Illuminating Engineering Society, March, 1911. This last paper contains references to a number of other papers on this subject.

W. J. Foster: The common use of 25 and 60 cycles in alternating-current work in this country makes it natural to discuss the question as one of comparison between these two periodicities. Inasmuch as periodicity of 50 cycles is superior to 60 for general use in building generators, I shall proceed to make the comparison between 25 and 50, and later give some points in which 50 is superior to 60 cycles in design of alternating-current generators.

In general the designer attacks his problem by deciding upon diameter at air gap. Several considerations have an influence, such as peripheral speed and length along shaft. As a rule, the diameter will be approximately the same for 25 and 50 cycles, except in generators of both small output and low speed, where a smaller diameter will be selected for the lower periodicity.

Considering the mechanical problems, the higher periodicity in definite pole machines is preferable in that the load on rim of spider is better distributed and smaller in amount at the points of attachment of poles.

Considering the electrical features, the higher periodicity is better in that less material is required, but not so good in being subject to greater eddy current losses. For generators of the same characteristics the dimensions at armature face, *i.e.*, the diameter and the length over magnet core along shaft, are the same. The slots in armature and the conductors in the slots may be made identical in the two periodicities. It is evident at once that the quantity of magnetic material in armature core for the 50-cycle generator will be only about one-half that in the 25-cycle, since the total flux per pole is just one-half and the quality of iron is now so good that the magnetic densities are limited by considerations of permeability rather than temperature. The copper in armature winding will be less for the 50-cycle because the pole pitch is only one-half, and, consequently the projecting ends of winding where the coils pass around from slot to slot, will be much less. The copper in the field winding will be less because the heat radiating surface is much greater, due to the fact of twice as many poles.

I have gone carefully into the design of a 5000-kv-a., 80 per cent power factor, 375 rev. per min. generator at the two

periodicities—25 and 50. In accordance with what I consider the best practise, I have made the magnetic densities, both in the teeth and armature core proper and field magnet core, about 10 per cent higher in the lower periodicity. The result is as follows (comparing the 25-cycle with the 50-cycle):

Magnetic material 50 per cent greater.

Copper (armature and field combined) 30 per cent greater.

Efficiency 0.2 per cent greater.

Established current on short-circuit—the same.

Instantaneous short-circuit 30 per cent greater.

Temperature rises:

On armature and field windings—the same.

On armature core—about 20 per cent less.

The comparison at higher speeds is more unfavorable to 25 cycles. In this connection it should be pointed out that 25-cycle generators of revolving field definite pole type are impractical above 750 rev. per min., whereas the limitation for 50 cycles is not reached until 1500 rev. per min.

In justice to 25 cycles it should be stated that this frequency has the advantage in very low speeds and small capacity, such as engine-driven generators of 50 to 1000 kw. at speeds of 300 to 75 rev. per min.—as a rule both in the matter of cost and characteristics.

For generators that are of both high speed and large capacity, such as steam turbine driven generators, there is a most decided advantage in the use of 50 cycles, as it permits of a speed of 3000 rev. per min., whereas the highest possible for 25 cycles is 1500 revolutions. As to the relative merits of the two frequencies in this class of work, practically the same conditions exist in the matter of quantity of material as in definite pole generators.

As to the advantages of 50 cycles over 60 cycles, they are such as: greater air gap clearance; greater pole pitch, permitting the selection of more slots per phase per pole in many designs; somewhat less danger of trouble from eddy currents; a speed of 3000 revolutions instead of 3600 for the highest speed, which is an advantage for most types of steam turbines.

In conclusion, I venture the statement that if all future work were to be restricted to some one periodicity, most experienced designers would vote for 50 cycles.

H. R. Summerhayes: The general tendency recently has been towards consolidation. Where a number of small plants exist, the tendency is to consolidate into a large plant, and several villages will make arrangements for a supply from one plant. Most of the small lighting plants in this country at the present time are operated on 60 cycles. As they are consolidated, the tendency is naturally to use the same frequency, and then, in larger cities, the 60-cycle is used more and more and the 25-cycle and lower frequencies are employed chiefly in the cases of special applications. A frequency of 25 cycles was selected for large systems originally, partly on account of

the use of synchronous converters and partly on account of the lower capacity of the transmission line, and also because the reactance drop was less. It is now considered that a greater reactance is an advantage instead of a disadvantage. As the systems are consolidated and as the size of the systems increases, we now have systems covering whole States, and the higher reactance at 60 cycles becomes an advantage in limiting the current flowing at short-circuits. I believe, therefore, that the higher frequency will come more and more into general use, and that the lower frequencies will be used for special applications, furnished by frequency changers, and the frequency changers will also have a use as synchronous condensers for effecting good regulation on the system.

Charles F. Scott: The problem which is so admirably presented here of 25 versus 60 cycles is not one to be answered by "yes" or "no." The subject is taken up under eleven different heads, and under each one of these either frequency may be used. A large number of examples is given. In each kind of service both frequencies are used. There seems to be almost no field which cannot be occupied by either frequency, the exceptions being the single-phase railway, in which 60 cycles is not acceptable, and certain kinds of illumination, notably by arc lamps, in which 25-cycles is not acceptable. Consequently, the problem is one which must be settled for each individual case by taking into consideration the large number of elements which are here presented and determining which are the predominating and important ones. It is a question like the old controversy between direct current and alternating current in which we have indulged so largely in the past, and which, like it, is answered with two answers, instead of one.

N. J. Neall: In any criticism of 25 cycles it should not be overlooked that this frequency is now being used for commercial lighting, and with considerable success. The reason for this lies in the development of special reflectors or shades, such for example as that of the Holophane type, which have been instrumental in eliminating the objectionable "flicker" which would otherwise occur.

It is of course true that 25-cycle arcs are decidedly objectionable from the illuminating standpoint; but owing to the development of the mercury rectifier, arc lighting on 25-cycle systems can in this way be satisfactorily handled.

It is at once apparent that for a large transmission proposition with a very big proportion of power load the adoption of 25 cycles throughout can be entirely justified.

J. R. Werth: It is interesting to correlate two of the ideas just presented by Mr. Lamme and Mr. Summerhayes: namely, the presence of high reactance, and, second, the advantageous use of synchronous condensers.

When voltage control by means of the latter is desired, the former is of material assistance. An analogy of this action

can be seen in the case of the railway synchronous converter with reactance. We automatically secure flat-compounding or over-compounding due to two factors: the amount of reactance in the circuit, and the degree of over-excitation of the synchronous machine.

These two factors are present when a 60-cycle synchronous condenser is operated at the far end of a transmission line (which, therefore, contains an appreciable reactance) and when the field of the condenser is over-excited and controlled by means of an automatic voltage regulator.

The point I wish to emphasize is that this voltage control may be secured with greater economy on a 60-cycle circuit than on a 25-cycle circuit. The synchronous condenser is cheaper, due largely to the higher speeds permitted by the higher periodicity. Also, the higher reactance is inherent, and, therefore, an additional external reactance does not have to be installed, as has been suggested for use on 25-cycle systems by Professor E. J. Berg.

E. A. Lof: There is a slight error in the paper as originally printed, in the curves for induction motors, in that they are shown drawn clear out to the left-hand ordinate, which should not have been the case.

For all the curves, with the exception of the ones for skin effect, the origin is in the lower left-hand corner of the diagram, and this will be clearly indicated when the paper is finally reprinted for the TRANSACTIONS.

The reason why no cost figures are given is not so much from a commercial standpoint as from the fact that such figures would be worthless, as they would only represent the average for a number of machines of different speeds, voltages, etc. The curves are only intended to represent the approximate ratio of the average cost of 25-cycle and 60-cycle machines.

DISCUSSION ON "EXCITATION OF ALTERNATING-CURRENT GENERATORS" (RUSHMORE), BOSTON, MASS., JUNE 28, 1912. (SEE PROCEEDINGS FOR JULY, 1912.)

(Subject to final revision for the Transactions.)

B. G. Lamme: I have only a few points to bring up in connection with this paper. On page 1566 is a table which I did not understand. For example, the constants given for single-phase and three-phase windings do not agree, and yet very frequently three-phase windings are used to give single-phase. However, I may not understand how these constants are used. In the method of calculation which I have been using, I do not have any fixed constants. I first work out the magnetic field distribution. From this I then derive the constants for each individual case. The use of a constant is all right in the hands of a skilful designer, if he knows how it is derived, but in special designs it is likely to be misleading. The table given probably refers to a standard type of machine in which the constant has been determined, and has been proved to be *constant* in all cases.

A second point is the value of K_w, the winding pitch factor, that is shown on page 1567. The curve shown is part of what is practically a sine curve. It is so close to a sine that it is almost impossible to find the difference.

On page 1569 the "Range of Excitation" is referred to, where it is stated that "with 125 volts excitation, the voltage should therefore not be allowed to exceed 125 volts at maximum load, 80 per cent power factor, and the corresponding no-load excitation should be about 70 volts." That statement can apply only to fairly well regulating machines; but for high-speed machines such as turbo-alternators where the regulation is made purposely rather bad, the ratio of 70 to 125 is much too small, and we find in practise that 50 volts at no-load is about right, with 110 at full load, which leaves a little margin for rheostat.

On page 1571, "Exciters with Commutating Poles," it is stated, "The reason for this is generally due to the fact that a commutating pole machine, when flat-compounded at 125 volts, has a rising characteristic when operated at voltages less than normal." I think that, while that is frequently true in practise, it is not necessarily true; because it is due partly to the fact that a machine at 125 volts is usually worked farther over the bend of the saturation curve than at lower voltages. Part of the over-compounding may be due to the presence or absence of local currents in the coils short-circuited by the brushes. When a machine with commutating poles is operated as a motor, and the commutating poles are over-excited, the main field of the machine is weakened as the load goes on, due to the local currents under the brushes. If it is operated as a generator, the local currents will tend to strengthen the field and compound it. At 80 volts, for instance, the magnetic circuit is less saturated than at 125 volts. If part of the saturation lies in the yoke of the machine, which is

usually the case, then this saturation will affect the magnetic circuit of the commutating pole, and more commutating pole ampere-turns are required at 125 volts than at 80 volts. Therefore the commutating pole will be over-excited at the lower saturations, and the local currents will tend to compound the machine. But I have seen many machines in which there was no evidence of this compounding action.

On page 1591 reference is made to the use of one exciter for each generator. That has been the practise in many large European stations, but judging from my experience, it is not an advisable arrangement in general. I think a better scheme is to put in one or two large independent exciters, to excite all the machines. However, if individual exciters are used, they can be adjusted to operate without rheostats in the main fields. With turbo-alternators, however, the total loss in the exciting circuit is generally so low that the rheostatic loss does not make much difference. There is some demand for large turbo-alternators with an exciter with each machine, but it is a practice that I do not think is right, and I have objected to it, so far as I could.

H. M. Hobart: This morning there seemed to be a pretty general agreement that it was better to have the ventilating apparatus distinct from the generator; that the generator could then be designed so as to be better for its purpose, and the ventilating apparatus for *its* purpose. I think the same argument applies in the case of the exciter. The plan of employing direct-connected exciters is very disadvantageous from various standpoints. It is hard to conceive of a worse practise, for obvious reasons which I will not take time to review. It is desirable to ascertain whether there is any clearly defined common agreement among engineers who have studied the subject thoroughly, as to having independent exciters. Mr. Lamme has voiced his opinion that that is the only reasonable thing to do, and if others would give their support to this plan I think it would help to discourage men from concluding that their individual requirements would justify them in using direct-connected exciters.

J. Lester Woodbridge: On page 1571 the statement is made that compound exciters are preferable, the main reason for this being that better parallel operation is obtained with compound windings, this being especially true where two or more machines of different size are to be operated in parallel. I suppose that refers to the question of stability, or the equal division of load between two machines, but I do not see how compound winding, that is, the series windings, can improve the stability over what would be obtained with shunt-wound machines, connected in parallel. The cause of instability in compound-wound machines operating without equalizing connections is the fact that if any disturbance occurs in one machine, such as a change in speed, which causes local currents to circulate between the

machines, the result is aggravated by the series windings. By using the equalizing connection, the same stability results as is obtained with two shunt-wound machines without the series winding, provided the equalizing connection has practically zero resistance. Any departure from this last assumption introduces some instability, due to the fact that some of the local current will flow through the series windings. Therefore I do not see how any better stability can be obtained with the compound winding than is inherent in two shunt-wound machines operated in parallel.

E. A. Lof: With regard to Mr. Lamme's remarks as to the advisability of using a few large units rather than a number of small ones, there may also be objections to such an arrangement. In one large central station the exciter equipment consists of both water-wheel-driven and motor-driven exciters, the latter being intended for the normal operation. Considerable trouble has been experienced from the motor-driven unit falling out of step, thus shutting down the whole system. This, however, might not have been the case if the exciter unit had been driven by an induction motor instead of a synchronous motor. With a number of small motor-driven exciter units, preferably operated from a separate alternating-current source, such a complete shut-down would, of course, be very remote, and this is evidently the reason why such a system of excitation has been provided in a number of recent installations of the largest capacity. In one particular plant which contained two or three large exciters the original equipment has been discarded and one small motor-driven unit has been installed for each main generator.

With reference to the single-phase slot factors, these values are under the assumption that the winding is distributed over the whole armature. If part of the slots are not occupied, the breadth of the winding is reduced and the values should be increased to approximately those given for a two-phase winding.

B. G. Lamme: In my remarks I did not refer to a number of small exciters as compared with a large one, but to two large exciters direct-connected with the generators.

Lester McKenney: I wish to emphasize the necessity, where automatic voltage regulators are to be installed, of using exciters designed especially for the purpose. It is of the greatest importance that the exciters have a voltage range considerably in excess of the maximum excitation requirements, that the range of excitation required by the alternator be narrow and that the time element of the alternator and exciter combined be as short as possible; as upon these things, largely, depends the success of automatic voltage regulation.

A considerable margin of exciter voltage is desirable, as when the maximum voltage of the exciter is called for the relay contacts remain closed and voltage regulation is no longer obtained. When operating near the maximum voltage the density

in the fields becomes high and large variations in field current are required for small variations in voltage, the time element is increased, and the operation becomes in general unsatisfactory.

A time element of less than from four to six seconds is desirable, providing it is not obtained by the use of excessive resistance in the exciter field rheostat, which greatly increases the duty of the relay contacts and impairs the operation of the regulator. The series field excitation should be limited to about 30 per cent of the total, as with higher percentages shunt field rheostats of excessive resistance are required for reducing the exciter voltage to the required minimum in a reasonable length of time.

In a great many cases, where automatic voltage regulators have been installed, the results have been disappointing, due to the lack of a proper appreciation of the instantaneous effect of the armature resistance and reactance upon the alternator voltage and of the effect of the time element introduced by the inductance of the alternator and exciter field windings. When these points are given consideration it will be evident that momentary fluctuations of voltage are to be expected during unusual disturbances.

It would seem, other things being the same, that compound-wound exciters would be somewhat more sluggish in their action than shunt-wound exciters, due to the damping effect of the local circuit formed by the series field winding and the external shunt. This, of course, applies only in automatic voltage regulation where the exciter field strength is varied as rapidly as possible from one value to another.

It is advisable, where belted exciters are used in connection with automatic regulators, to make the pulleys of more liberal proportions than are usual in ordinary applications, as the exciters are subject to higher excitation and greater overloads in time of trouble.

Discussion on "Corona Losses between Wires at High Voltages" (Harding), "The Law of Corona and Dielectric Strength of Air—II" (Peek), and "The Electric Strength of Air—III" (Whitehead), Boston, Mass., June 25, 1912. (See Proceedings for July and June, 1912.)

(*Subject to final revision for the Transactions.*)

John B. Taylor: Toward the end of Mr. Peek's paper he speaks of the mechanical vibration of wires. The photographs reproduced in his paper, Fig. 41 and 42, I think are easily enough explained, that is, the wire is pulled first on one side, and then on the other, by electrostatic forces, and if the wire is approximately attuned to the frequency, closely enough so that it can be made to vibrate with that frequency, you have this characteristic of negative on one side and positive on the other. Mr. Peek speaks of the vibration noticed on a pair of 20-mil. steel conductors, 500 ft. (152 m.) long, strung at 10-ft. (3-m.) spacing, which I think must have been due to something of that condition.

I saw that myself one evening. We were out to take some photographs, but on putting the voltage on, the wire would begin to sway, and after a while it swayed so much that the particular photographs we were after could not be taken, although we got some interesting photographs of this swaying. It was at first supposed it was due to some vibration of the towers, as we were pretty close to the towers, but on taking the voltage off it was found that the swaying stopped. On five or six different occasions the voltage was put on, and the wires began to swing at a slow period of about sixty swings a minute. Obviously, the 60-cycle attractions could not have had anything to do with this wire swinging in a one-second period, and just exactly what caused it is still a mystery, although my own opinion is that there was something on the power line, which was supplied by the circuit at that time, which caused a small variation in the voltage, which variation happened to fall in synchronism with the period of the wire, as it happened to be on that particular day.

I do not know whether that has been observed on other occasions, but it seemed to me that the only way to explain the small vibration was that there was a small variation in the voltage of the circuit, which fell in with the period of the wire, although the voltmeters do not show any indication of the cause of such vibration. I had a suspicion that it was due to an air transformer, or some similar apparatus, on the same line, which called for a little more current than was normally running on the line.

In both of these papers we have a line of investigation somewhat different from the early corona papers, different from the subjects and particular lines of investigations which were taken up in those papers. Most of the early investigators, I think, tried to get limiting values on which to plot the curves. Of course, that is in order to determine the loss, but I think investi-

gations like these are sooner or later going to show us a lot more about the real inherent nature of the corona, and, as in everything else, when we know just a little more about the whys and wherefores of it, we will be in a position to get around the limitations and reduce the losses.

These observations are very interesting, and I think it is next in order to combine the quartz lens with the stroboscope, in fact, to use all the tools which are available to any scientific investigator, when you want to get right down to the things which are either too quick or too small to see, but are in any event, beyond the range of our normal senses.

A. E. Kennelly: The very interesting and important papers on corona this year have apparently reached a stage further than we reached last year.

It seems now to be really agreed that the corona and power loss becomes a parabolic law, which goes up as the square above a certain critical voltage, and the interesting points presented here, outside of the confirmation of that law, are as to what may be the scientific characteristics of the phenomena rather than the practical characteristics.

In the first paper of Professor Ryan, it appeared, according to his observations, that the increase in gradient on very small wires was inversely proportioned to the radius, that is to say, the visible gradient was 30 kv. per cm., plus 10 divided by the radius, that is to say, a hyperbolic formula, approximately, over a considerable range in his observations.

As I understood it from Mr. Peek's results, his recent observations do not show that formula, but 30 plus q over the square root of the radius.

Another interesting feature of Mr. Peek's paper is his use of the stroboscope in obtaining pictures of wire in corona. Now I understand why we may have a physical basis for saying that electricity is red or blue, and having one conductor painted red and another blue—although the red in this case is negative and blue the positive. This is the reverse of the ordinary convention, but at last we have a physical basis for the color. Is it to be supposed that the blue is due to the more active operation of negative ions and the red due to the heat produced by the heavier positive ions, or is there any explanation for this difference in color?

Mention is made in Mr. Peek's paper that the appearance of the phenomenon is as though the blue electricity was streaming out from the positive wire into the surrounding space and received into the negative wire, as though the electricity was streaming out of the positive wire, and going into the negative wire, the kind of phenomenon we have in an electric current. Is it not possible that the phenomenon witnessed in the stroboscope may be called for by the negative electricity passing out of the air and then streaming into the positive wire? There is nothing in the stroboscopic picture to show whether the flow which appears

to take place is projected outward from the positive wire into the air, or from the air into the wire, and a few words on that point would be very interesting.

In regard to Mr. Harding's paper, it is interesting to see the agreement of his observations with those given by Mr. Peek, and one of the great values of Mr. Peek's paper last year was the perfect clearness of his formulas. There was no doubt as to what they meant. Attached to each formula was the unit in which it was written, and attached to each symbol was the meaning of such symbol, and we owe him thanks for that clearness and attention to detail. I think the great progress made this year is partly attributable to that fact.

The agreement reached by Mr. Harding and Mr. Peek is very interesting. I would like to get Mr. Harding's opinion as to whether the large correction for the rack is not a little dangerous, Would not it be safer to experiment with a smaller correction of this kind, to have a larger line and shorter racks, so as to have a small correction to subtract from the actual observed losses?

C. P. Steinmetz: I wish to say a few words first on Mr. Harding's paper, in reference to one conclusion contained in it, and that is the quadratic law *below the critical limit.* These laws have first been derived as empirical laws. However, even an empirical law cannot be accepted as an approximation, unless it appears rational in its application. If you look at the curve of the quadratic law *above the critical limit,* you see that it points to a definite zero value at 30 kv. per cm. as the disruptive gradient, and is rational. But the quadratic law below the critical limit gives values which become negative at the higher spacing. This would lead to the conclusion that at the highest spacing, corona begins below zero, that is, it is there already at zero voltage, which obviously is not the case. In this case, therefore, it seems merely accidental that the points lie on an approximate quadratic curve, or rather that the quadratic curve is an approximation of some actual curve.

Mr. Peek's data a year ago did not give this quadratic curve, for losses near the critical voltage due to irregularity, but seemed to be best represented by an exponential curve. If you will look at this exponential curve, which contains the square of the voltage in the exponent, you will find that the first approximation of it will be the quadratic. However, the exponential curve would be only very approximate, because, while as the probability curve it is rational in applying to the irregularities on the conductor, it would only apply to those irregularities which are entirely irregular, but if there was some regularity in the irregularity, as, for instance, a ridge in the conductor, then there would be some regular arrangement which would disagree with the probability curve and give a quadratic curve of different constant.

The two other papers, those of Mr. Peek and Mr. Whitehead, continue the investigations of last year, to a considerable extent,

mainly with the object of extending the range of application of the formulas given in the papers of last year. The papers of this year cover a wider range, and give a rationalization of these formulas, that is, they begin to give the theoretical and physical reasons why these formulas apply. The most interesting part is that these papers first give the separation of the alternating-current corona into two parts, the positive corona and the negative corona—Mr.Peek by photograph, by means of the stroboscope, and Dr. Whitehead by means of ionization. This is extremely interesting. As the positive and negative coronas are different, it appears probable that they also begin at different voltages, and, furthermore, that the losses at the positive and negative coronas are different. Now, look at what that means in engineering. It would mean, if the losses at positive and negative coronas are different, that there would be, if the line were perfectly insulated, a unidirectional electrification on the line which would increase until the potential difference of the negative against ground would be so much higher than the positive against ground that it would make the losses of the two equal.

There is mention made in the paper of a number of phenomena which show under certain conditions. There is a difference in the energy discharge in the air from the positive and negative coronas, and there would, therefore, be electrification on the line which should appear. It would mean, however, that if you could artificially produce the counter-electrification, by connecting unidirectional potential between line and ground, you should be able to extend the operating voltage, though possibly by a negligible amount only, before the corona losses appear. You see it is a very interesting field which is opened up here.

I want to refer to one point more, regarding the statement made by Dr. Whitehead, that there is no evidence that the free ionization of the air has any effect on the corona and that there is no such effect. I do not believe there has been any test made, or any evidence given of such a nature, under such conditions that an effect of the free ionization of the air should be expected. Whether the free ionization of air is great or small, as long as there are any free ions at all the corona should appear at the same voltage, at the same potential gradient. The only difference which the free ionization would make, or the only effect which it could have, would be rather in the rapidity with which the corona appears, in the time required to produce the corona. This free ionization of air could have an effect only on the transient corona, but not on the corona under permanent conditions, as in alternating circuit, where the free ionization of the air with which the corona at each half wave starts is by necessity the same as the residual ionization of the preceding half wave. So, there is no evidence thus far brought forward that the free ionization of the air has no effect upon the appearance of the corona, and it would be interesting to take that matter up and make a thorough investigation.

C. Francis Harding: We have two distinct types of papers before us. My paper did not attempt to go into the causes of the phenomena, but simply to point out how very easily and correctly, I think Mr. Peek's results can be applied to practical transmission line design, and I want to second Dr. Kennelly's congratulations to Mr. Peek for presenting his data in such form, particularly the formulas, that engineers in designing high-tension transmission lines can readily predict, with sufficient accuracy for practical purposes, the probable corona loss, and therefore the necessary spacing and size of cables to avoid such losses.

With regard to Dr. Kennelly's suggestions in reference to the large rack losses, I wish to point out one feature in the paper namely that the greater portion of these losses represented by the lower dotted curves are not on the rack itself, but on the lines connecting the transformer to the experimental transmission line, and were therefore largely corona losses on wires, although obeying some different law, possibly, than the corona losses on the transmission line itself, which could be controlled. I think if the feeder loss could have been reduced it would have been advisable to have done so. However, as I stated, the two dotted line curves are not quadratics, and the curves which are expressed in the full lines, representing a subtraction of the other two curves, are quadratics, the points falling very accurately on the curves. It seems to me, therefore, that we are getting very satisfactory results by that method, even though the subtracted loss is relatively large.

With regard to the suggestion of Dr. Steinmetz, this result, of course, is an empirical one, as he states, and the empirical data seemed to fall on a quadratic curve below, as well as above, the critical voltage, in this particular case. That does not mean, of course, that they will fall on quadratic curves under other conditions. The law below the critical voltage is, however, of little interest to the practical designer of the transmission lines, and more attention has been paid to the curve above the critical voltage by the investigators than to the portion of the curve below that voltage. However, the wires used were new, perfectly smooth wires, direct from the factory, and that fact might have had something to do with the coincidence of the points with the quadratic curve below the critical voltage.

F. W. Peek, Jr.: From the formulas given in "The Law of Corona—I" the corona characteristics of practical transmission lines can be accurately predetermined. While the present investigation is being carried on partly with the view of getting at the fundamentals of corona formation and loss, the engineering and practical side is always kept prominently in view. Many new practical data have been obtained, and, it is hoped, also, that some steps forward have been made in the theoretical direction.

The stroboscopic study has brought forth many interesting questions. Dr. Steinmetz has pointed out one of these, that

as the result of the different apparent starting points of corona at different halves of the wave the line would probably be gradually increased in potential of a given sign against earth.

Referring to Dr. Kennelly's discussion: The formula for gradient is

$$g_v = 30\,\delta \left(1 + \frac{0.301}{\sqrt{\delta\, r}} \right)$$

The other formula is not for corona starting point, but for apparent gradient, g_s, at spark-over. It is true the stroboscopic photographs do not show the "direction of flow;" one is simply given the impression, especially in the case of the point discharge, of, for instance, a steam jet discharging at the positive toward the negative. The statement is made rather as to the appearance in a descriptive or visual sense. More data on the direction of flow, etc., have been obtained, but are not as yet in form for publication.

In Mr. Harding's paper, it is very interesting to see that his results, on the whole, check so well my formulas of last year. There are one or two points with which I can hardly agree. One of them concerns the accuracy of the method of power and voltage measurement advocated by Mr. Harding. With a well designed transformer and exploring coil we found by actual test that the voltage as indicated by the coil is extremely accurate. Watts measured on the high side also always checked with watts measured on the low side when corrections were made for transformer loss. The spark gap is not suitable for voltage measurements of this sort as there is a variation from day to day of as much as 15 per cent. If the exploring coil is not so placed in the transformer that it will measure the voltage correctly, it will not indicate the power factor correctly on the oscillograms. Thus by this spark gap-power factor method there are two chances of considerable error. Besides accuracy, the wattmeter method has the advantage of making a great number of readings possible in a short time. The $\Sigma \Delta$ method of reduction of data is not especially applicable unless a considerable number of readings are used.

It is generally difficult to make exact comparisons of loss as calculated by the formulas and loss measured on operating lines, because in most of these measurements all of the conditions are not given, such as variation of altitude along line, voltage rise at no load, temperature, etc. For instance, unless the effect of voltage rise along the line at no load is taken into account the measurements will show higher loss than the formulas. When these variables are considered as closely as possible the check is quite remarkable, as shown in Figs. 1 and 2, which give a comparison of curves calculated from formulas and readings taken by other investigators. The agreement would probably have been more exact if all conditions, such as temperature at different points of the line, etc., were exactly known. A very interesting

check of the formulas is also given in a paper by Faccioli* before the N. E. L. A. on measurements of the 140,000-volt line of the Au Sable Electric Company.

Dr. Whitehead has in his paper brought forth, as usual, some ingenious new experiments. I refer especially to the section on "The Ionization Due to the Corona." Such work as this adds greatly to our knowledge of the mechanism of the break-

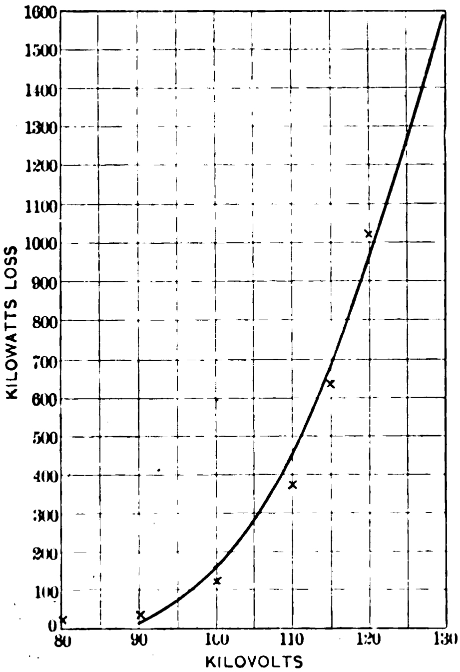


FIG. 1.—COMPARISON OF CALCULATED AND MEASURED LOSSES

The x points are measured values. The drawn curve is calculated from the corona formula:

$$p = \frac{k'}{\delta} f \sqrt{\frac{r}{S}} \left(e - g_0 \, m_0 \, r \, \delta \; 2.302 \; \log_{10} \frac{S}{r} \right)^2 10^{-5}$$

Diam. of wire 0.375 in. (No. 0 cable), spacing 124 in., three-phase, length of line 63.5 miles.

Note—Test by Faccioli on corona losses, Shoshone-Leadville transmission line. Tests made on operating line three-phase, and at high altitude. Check interesting because of the number of variables taken into account.

down of air under dielectric stress. The stroboscopic photographs which I have shown, as far as the investigations overlap, indicate much the same general results, such as different starting voltage of positive and negative coronas, etc. The stroboscopic photographs show a decided difference in the appearance of

*"Corona in High-Tension Lines"—N. E. L. A. *Proceedings*, June, 1912.

corona on the positive and negative part of the wave. Further interesting data have been obtained as a result of the stroboscopic study, but are not at the present time available for publication.

The manner in which the air density factor enters into the expression for visual gradient was predicted long before experimental data over a great range of δ were obtained. The formula must take the form given if the energy theory of disruption

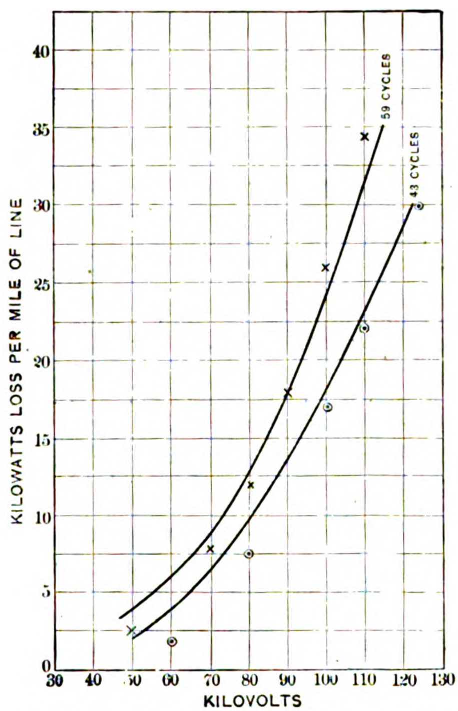


FIG. 2.—COMPARISON OF CALCULATED AND MEASURED LOSSES

The x and 0 points are measured values. The drawn curves are calculated from the corona formula (see Fig. 1.) Diameter of wire 0.064 in., spacing 48 in.

Note—Tests made on short line by A. B. Hendricks, 1903-1904. This shows check at two frequencies.

brought out in "Law of Corona I" is true. This is further discussed in "Law of Corona II." The observed results in Tables I and II follow this law, but the data range is not great as Dr. Whitehead states. Other data further confirming this law were given in the data appendix to this paper, which appendix was not printed. In the table here given, δ is taken over a very great range. The check of the law is apparent without further discussion.

δ	g_v observed kv./cm.	g_v calculated from formula $g_v = 31\,\delta\left(1+\frac{0.301}{\sqrt{\delta\,r}}\right)$
0.023	3.3	3.47
0.074	7.2	7.33
0.116	9.7	9.90
0.216	15.5	15.30
0.38	23.7	23.20
0.513	30.0	29.1
0.667	36.8	36.0
0.83	43.0	42.7
1.02	50.9	50.3

Radius of wire 0.254 cm.

J. B. Whitehead: Mr. Peek has performed a most important service in carrying out his experiments on the influence of temperature on the starting of corona. This is a line of work which has been very much needed ever since we have been studying this phenomenon. With the facility which characterized his earlier paper, Mr. Peek has converted his various results into formulas, thus proposing several interesting laws. In discussing the effect of the variation of the density of air on the critical electric intensity, Mr. Peek states that his results are explained if the density factor enters in both numerator and denominator of the expression for the critical intensity. Now, the results as plotted in the curves of the paper do not, I think, bear out that conclusion. If the density factor is used only as multiplying factor and stricken out of the denominator, you will get a curve which is as good as Mr. Peek's curve for the results given in the first table. The agreement is not, however, quite so good for Table II. But it should be noted that the real test of the formula lies in observations at low density where the curve departs from a straight line, and Mr. Peek has no observations in this region. I have discussed this with him and he tells me that many of the results have been stricken from the original paper by the Institute owing to limited publication space. It is very desirable indeed that in the proposal of a law so important as this, all the results should be given, and I hope that they may be obtained and published at some later time. To my mind they are more important than the development of the formulas expressing the results of sparking distances between water and oil covered wires. The conditions under which oil and water occur on the surface of wires are so varied and irregular, that it is questionable whether an empirical law will prove of any particular value.

I believe, however, that the downward trend of the curves of Fig. 4 at low densities is correct. We have just completed some investigations in our laboratory, which will soon be in print, in which we have carried the pressure much further down than those described in my earlier papers and those reached in Mr.

Peek's Fig. 4. We have shown, without question, the downward bend of the curves. The lines are nearly straight at values of density above one-half an atmosphere, making it very difficult, indeed, to predicate the law unless the pressure is reduced well below this value.

Dr. Steinmetz has made a suggestion in the language of the ionization theory in possible explanation of the larger values of intensity at which corona starts on small wires. I hope this indicates a greater sympathy with this theory than he has shown in the past. It is now widely accepted by physicists and undoubtedly offers better prospect than any other of an explanation of corona phenomena. He has, however, given the impression that my paper states that the presence of natural ionization in the air has an influence on the starting of corona. It must be evident to anybody who has considered the theory of secondary ionization that free ionization as it occurs in the air can never have anything to do with the starting of corona. Every comment I have made, and every experiment I have undertaken, has indicated that free ionization in the air has nothing to do with it. This fact is emphasized in the present paper because within the last year a paper has been presented before the Institute and discussed, in which it was maintained that free ionization has influence on the starting of corona.

A. S. Langsdorf (by letter): Mr. Peek's interesting and valuable paper has additional interest to the writer because the stroboscopic examination of the corona so fully described has anticipated a similar experimental study which he had planned. The idea that such a study might shed light upon the nature of corona formation around conductors subjected to alternating e.m.fs. was first suggested to the writer by an extended experimental study made by Professor Francis E. Nipher of Washington University, the results of which have been published from time to time in the *Transactions* of the Academy of Science of St. Louis.* Inasmuch as the results of Professor Nipher's work are less well known to electrical engineers than their importance warrants, it seems desirable at this time to submit to the Institute a brief summary of that part of his work and conclusions which is of particular interest in connection with the present paper.

All of the work referred to has been done with a large 8-plate influence machine, using discharge terminals of various kinds, but mainly (so far as present purposes go) the usual spherical brass knobs. Viewing the discharge in a darkened room under steady operating conditions gave results equivalent to a stroboscopic examination of an alternating electric field with a fixed setting of the stroboscope. It is interesting to state that Mr. Peek's photographs are in exact accord with those published in Professor Nipher's papers.

**Transactions* Academy of Science of St. Louis, Vol. XIX, Nos. 1 and 4; Vol. XX, No. 1; Vol. XXI, No. 3.

A long series of experiments involving the study of positive and negative discharges on photographic plates, which yielded many beautiful figures somewhat similar to the familiar Lichtenberg dust figures, taken in conjunction with other significant results, led Professor Nipher to the conclusion that the chief factor in all the phenomena involved is the negatively charged electron, and that the so-called positive ion consists merely of an atom that has been deprived of its normal store of electrons. This view is essentially the "one-fluid" theory of electricity. The figure traced on a photographic plate by a positive discharge always shows a characteristic tree-like pattern branching out from the positive terminal; *or* (and herein lies the key to the problem) it resembles much more the map of a river and its tributaries *draining into* the positive terminal. On the other hand, the figure produced on a sensitized plate by a negative discharge has a characteristic fan shape which leads irresistibly to the idea of a pressure discharge from the negative terminal. Looked at in this way, the influence machine takes on the aspect of a pump whose negative terminal is in a state of compression and whose positive terminal is in a state of rarefaction. This view, to the writer's mind, is much more illuminating than the common one of a double discharge, positive and negative.

Thus, imagine that the knobs of an influence machine, placed in a darkened room, are fully charged, the voltage being high enough to start the corona but less than sufficient to cause a disruptive discharge. The negative terminal, on the side facing the positive, will be surrounded by a thin layer of reddish light; the positive will be the apparent starting point of a tuft of bluish light (the positive brush) reaching toward the negative. As the voltage is increased, thin white streamers flash through the positive brush, the latter lengthens, thereby shortening the Faraday dark space between it and the negative glow, until ultimately a spark passes. But before the final breakdown there are two distinct currents of air, one moving from the negative towards the positive, the other from the positive to the negative; this has been shown by means of a small windmill built entirely of mica and hard rubber. By the one-fluid theory this can be explained as follows: The air molecules in the immediate neighborhood of the positive terminal are partially drained of their negative electrons to supply the deficiency created by the "suction" of the electrical pump; they then become "positively" charged and are repelled. Colliding then with neutral molecules, ionization takes place and the more remote molecule hands on its negative charge to the one nearer the positive terminal. Electrons are then traveling toward the positive, while their carriers, the positive ions or air molecules, are moving the other way, much as a runner might jump from cake to cake of floating ice. The jostling of the air particles is then responsible for the light of the brush discharge. At the negative terminal, on the other hand, the negatively supercharged metal passes on to the surrounding air layer some of its electrons, which then travel across

the dark space (the air acting as carrier) to supply the deficiency at the positive end. In the dark space the air particles do not have the to-and-fro motion above referred to, hence there are no collisions and no light.

It is commonly believed that the formation of the positive brush in a direction from positive to negative is an evidence of a true positive discharge, instead of a negative discharge in the opposite direction as described above. But Professor Nipher points out that this observed motion, whose rate of propagation (in a long exhausted tube) has been found by Sir J. J. Thomson to be of the order of that of light, may be only an optical illusion; for instance, if the rate of recession of Niagara Falls were extremely great, the river would appear to move up-stream, whereas the real flow is actually the other way.

This theory of a negative "compression" and a positive "rarefaction" satisfactorily explains a number of other observed phenomena. Thus, if the discharge knobs of a machine are set so that disruptive discharges pass freely between them, the introduction of a large sheet of copper between the knobs, and at or near the positive, will immediately suppress the sparking, whereas the same sheet placed at or near the negative will have no effect whatever. Since the average potential gradient is the same in both cases, this fact apparently points to the formation of corona at different potentials at the two terminals, the negative requiring the higher potential.

Corroborative evidence of the suction effect at the positive terminal is furnished by any Geissler tube having a twisted form. The positive glow readily finds its way through all the intricacies of the tube in a way that is strikingly different from the obvious pressure discharge of a cathode stream, as in a Braun tube. Again, an X-ray tube with grounded anode and with its cathode connected to the negative terminal of a machine whose positive terminal is grounded, will work satisfactorily, whereas it will not work, or only fitfully, if its cathode is connected to the positive, the negative end of the machine being grounded; but if the cathode of the tube is grounded and the anode is connected to the positive terminal, the results are as good as in the first case. In this connection the interesting suggestion has been made that the difference between positive and negative discharges in medical therapeutics may bear the same relation to each other as do cold and hot applications.

It is interesting to note that Mr. Peek's conclusions can be brought into accordance with the above theory by interchanging the words "positive" and "negative" in the italicized sentence at the end of Section X—"Stroboscopic Study of Corona" in Mr. Peek's paper. This sentence would then read:

"The corona loss seems to be in the form of a 'conduction' across from negative to positive, always starting from the negative conductor—thus starting alternately at each half cycle, from one conductor, then from the other."

Discussion on "Industrial Education" (Committee Report), Boston, Mass., June 27, 1912. (See Proceedings for July, 1912.)

(Subject to final revision for the Transactions.)

Henry G. Stott: The work that we are doing in New York in connection with the companies which I represent, is a very modest one, but one which was forced upon us by very peculiar circumstances. We have men who are trained for switchboard operators in railroad work, who handle a large amount of power, and these men are brought in with practically only a common school education and are taught the ordinary methods of operation of switchboard apparatus, taking care of the apparatus, etc. We found after training up men in this way that they became highly expert, although they had apparently no theoretical knowledge of what they were doing. However, a day of reckoning came to us when something went wrong with the operation or some trifling connection was broken, and these men failed lamentably. After a few experiences of that kind we discovered that no matter how well a man was able to carry on his routine duties, assuming everything was in first-class order, the least disturbance of that routine upset his whole idea. He was only an automaton. He could not think for himself. We thought we were using, perhaps, too poor a class of men. We tried a number of men trained at technical schools but it became very manifest that men who had received technical school education, while they met all the requirements of the case, could not be held there and we could not expect to hold them in work which soon becomes monotonous. We finally came to the conclusion that it would be necessary to establish a class to find out whether a man was an automaton or whether he had been really thinking and reading.

The work started in this way, but we went on with it as we found there was some very good material in the men and it gave us an insight into men's characters which we could not get in any other way. We started in the school by putting in the same kind of apparatus which men had to handle in their every-day work, with all the wiring and apparatus exposed. One of my assistants gave the instruction and began at the beginning of the electrical work, and found that the men took great interest in it.

After trying this out for about a year we found that we were getting inside information in regard to the men's characters, and their way of thinking, which was extremely valuable to us in promoting them. Promotions are now made from the bottom up. We then established the rule that unless a man took this course and passed the examination he could not be promoted. Nothing would be done to interfere with his present position, we announced, but he could not hope for promotion unless he took this course and passed the final examination. This immediately segregated these men into two classes; those who had

no hope of promotion, who were indifferent, and those who were ambitious and wanted to get along. It has thus been the means of telling us which men were best fitted for promotion.

The course is a simple one, a rudimentary course in mechanics and physics, then going on to show how current is generated, etc. We have a good laboratory there, showing how measurements are made, and calculations of various simple problems are made. In other words, a man is being taught to think and reason for himself, not to simply obey rules, because he is told to do so. The whole endeavor in the department which I control is to avoid arbitrary rules, to encourage a man to act on his own judgment as far as possible. In this way we have achieved results by this simple course which I don't think we could have done in any other way. By encouraging these men to take courses more advanced in other institutions, we got a few into college, and I think they will make their mark in life.

It has been the purpose of the company to find out the point of view of the man, whether he was simply there to get his pay at the end of the week, or whether he was ambitious enough to study and devote his time to progress. That has gone through a process of evolution, as I have said, so that it is a fairly good course of instruction now, and any man who leaves us is capable of performing good service in any company.

J. P. Jackson: May I ask Mr. Stott where his school gets the men—what the class of men is that he gets?

Henry G. Stott: The majority of men that we get have simply been through part of the grammar school; a few through high school, but as a rule with only grammar school education. We started in at one time to get men educated in technical schools, but naturally the monotony of the work, eight hours' work, seven days in a week, with of course a day off now and then, was too great to expect a man to remain there who had spent time in getting a scientific education. They would stay a year or less and then leave us. So that practically all the men whom we put into these positions for operators are those who have had only grammar school educations.

A. L. Williston: A great deal has been written or spoken from the public platform regarding the pressing necessity for industrial education, until it seems as though every thoughtful person must understand. And yet, as I work in this field, I find that we have not yet begun to make an impression on most persons of the seriousness of the need for this kind of work. As engineers, we are all interested in efficiency; and we are interested in the conservation of natural resources; and we are interested in all things that tend toward the greater economy in the utilization of all forces. As we commence to study actual conditions in almost all our large industries, we find waste of material, we find loss due to inefficiency in the use of power and machinery; but, gentlemen, as we study the conditions more closely we find that these losses are almost insignificant compared

with the greater human losses in almost all organizations and in all the industries.

These human losses are of two kinds; first, those losses that arise from the mistakes, the errors, the blunders, the waste of time from not knowing what to do, or from not knowing how to do the work in hand in the right way. Such losses, as we all know, are great enough; but a second type of human losses is, I believe, still greater. This includes the waste of human energy that comes from having so often the wrong man in any particular job, having no natural aptitude or taste for it; and the waste that comes from having the great majority of men without any real vision of future possibilities that lie ahead of them, and, therefore, without ambition to do their work with the same spirit of energy and excellence as, when youths, they put into their play. It is the lack of ability to see and understand what is ahead, the lack of vision of the possibilities beyond the present that, more than all else, makes work uninteresting and makes workmen feel that it is not worth their while to do their best or cooperate cheerfully and loyally either with individual employers or with the corporations that are furnishing them the opportunities for work.

If we could only estimate the value to society of having all the young people of the rising generation selected, or sorted in some way, so that the right persons would get into jobs for which they are fitted and for which they have some particular ability and taste; and also could estimate the value of having all of these persons given the spirit that would make them feel that their work was worth putting their hearts into, and could add to this the value of special training that would enable them to do their work with skill instead of with indifference, I think we all would appreciate that in comparison all the other efforts that we have been making in the past toward increased efficiency would seem small.

In discussing types of vocational schools and what vocational schools may accomplish, emphasis is too frequently placed upon the curriculum and upon details of methods of instruction. To my mind these are important, but there are at least two other things that are more fundamental and important. First, it is absolutely essential at the beginning to get the right boys to work on. If you are going to train young persons for a given industry, for example, to train them to be machinists or to be switchboard operators, or what not, it is of the utmost importance to select persons not only adapted to this kind of work, but also to select persons who, because of their natural environment, their previous life experience, their home traditions and surroundings, will look forward to the kind of life and future to which the particular vocation will probably lead with enthusiasm, eagerness and interest. The first and all-important problem, therefore, for the vocational school to solve is to get the right fellow into the school at the beginning. This is not easy, in fact it is extremely difficult; and there are very few precedents or guides to

go by. It is possible, however, as there are men who have had experience in selecting from the great mass of untrained people who are coming out of the elementary schools every year, those who will be, with training and experience, well adapted to different lines of work. Every capable factory superintendent employing a large number of young persons and every experienced employment director has some skill in this kind of selection. Men with such experience are needed in vocational schools to advise boys and girls regarding the future possibilities that are open to them, and to select from the applicants for admission those who by natural ability, home environment, etc., are well fitted to succeed in the several lines of work for which the school offers courses of instruction.

The thing of next importance is that during the period when the boys and girls are in vocational schools, they should, in addition to the manual skill that is needed and the elementary technical knowledge that is necessary to enable them to effectually use such skill in their chosen vocation, receive the kind of industrial discipline that will enable them to fit into their life work as efficiently as possible and also that they should have their ambition stimulated by accurate and intelligent appreciation of the opportunities that will be likely to be open to them later. It is entirely possible to develop in school an atmosphere which will give just as good industrial discipline as any shop. It is possible to select tasks and occupations in the school which will cultivate a right attitude toward work, a spirit of co-operation with one's employer and those other qualities of character which are essential for the best success in after life. And these things are more important in my judgment than are the questions how we teach practical mathematics or elementary applied science, or of how many hours of shop practise of one kind or another be included in the curriculum. Yet, when we get together to discuss matters of industrial education, I find, too often, we spend our time on the latter questions of details regarding the curriculum and too seldom on the correct methods of getting the right boy to work with, or the best ways of developing in him the particular qualities of character and manhood that his chosen vocation requires.

To some persons what I have just said may sound as if I were repeating what has always been the aim of all good schools. This, however, is far from the fact. Until very recently, and with very few exceptions, no schools have made a serious attempt to analyze the different vocations and to find out what particular qualities of character are essential to each, and no schools have seriously endeavored to develop the particular qualities that a chosen calling requires. It is this specialized kind of character-building which is the important function of the vocational school. There is in this country and abroad experience enough to prove beyond a possible doubt that this is not a visionary idea but is entirely practical if we set ourselves seriously to the task.

It is not necessary for me to take time to tell you gentlemen of the American Institute of Electrical Engineers or of the teaching profession—all of you earnest advocates of engineering education and of all the higher types of industrial schools—that mechanical skill is a good thing, or that technical training is a good thing, or that the spirit of open-mindedness, which makes one always eager to search for truth and a better way, is a good thing. To you I have only to suggest that in the field of trade teaching mechanical skill and elementary technical training adapted to the needs of the boys who may not have even a complete grammar school education, and the spirit of open-mindedness to new methods and new ideas are as useful, in relative measure, as we ourselves have found them in our own particular field in the higher departments of education.

Albert L. Rohrer: Tolstoi was very fond of describing labor as being under four heads, the first being that of muscular labor such as the ordinary laborer does, building roads and carrying the hod; the second class is that of the hand and wrist; done principally in factories; the third is that of the mind as shown by the work of the engineer; and the fourth is the labor of coöperation, that is, of all classes of labor working together, team work, as we are pleased to call it now. Until now both societies have been concerned from time to time in discussing the third class, the work of the engineer, the training of his mind, and the result of his work. Both societies I say, because one society has discussed the education of the engineer, the man who is to do the thinking, the other society has discussed his work; but it seems to me that the second class of labor, that of the hand and wrist, is of equal importance, and I am very glad indeed to see it given such an important part in the program. It well deserves and merits the joint session which is being held to consider it.

Now the problem of training the hand and wrist has been attacked from a great many view points. A great deal of good work is being done. The report of the committee just made indicates to you what has been accomplished, and I believe and agree with Professor Slichter that any man who takes the time to inquire into the topic at all will become enthusiastic. And I think it is the duty of every engineer to get interested in this problem. He can serve his locality and his country to very great advantage by getting interested in the situation and assisting with his good judgment.

Professor Jackson has asked me to describe briefly the work at Bridgeport which was referred to in the report of the committee. I spent a very interesting day there some time ago, and to any of you who are interested I think a few hours, even, spent in inspecting that school will serve to fill you with enthusiasm.

The peculiarity about the Bridgeport school and the school at New Britain is that the two schools were started and are conducted by the state of Connecticut. The state alone is doing

it, and the schools are doing some real constructive work. For instance, the school at Bridgeport, which I inspected, is located in a factory building. That gave me a very good impression at first sight. There is a certain atmosphere that prevails there which you could not possibly get in a school building. Four different branches have been taken up: that of metal working, or machinist; of carpentry and pattern making; of printing, and that of sewing. They have been particularly fortunate, I think, in selecting their teachers. They are all journeymen. They have attacked the problem, you see, from the standpoint of the practical man, and not from the schoolmaster's idea, and I think in some cases where the problem has been attempted by schoolmasters alone that it has not worked out so satisfactorily. These men at Bridgeport are all enthusiastic. They also have two ladies who are in charge of the sewing division and they are really accomplishing things too.

One feature impressed me very favorably in talking with the boys, and inquiring into what they had been doing.

The boy does not usually know what he wants to do. Mr. Williston has referred to that. They are given an opportunity there to try themselves out, which is a very important thing. Several of the boys had tried two or three different trades. One boy thought he wanted to learn the printing trade. He did not work out well at that; he then thought perhaps he might want to be a carpenter. He entered that division for a time, but did not work out very satisfactorily there, and finally he landed in the machine shop where he is doing very good work indeed.

The work is all practical. They don't do any show pieces which are put in a case or laid on a table. Everything that the boy does is put to practical use. The city of Bridgeport offers some very good opportunities for that work. The business of Bridgeport is very largely the metal trades, and it comprises a large number of small factories. Everything that they do in the way of carpentry and printing and sewing can be carried into any city in this country. The carpentry division took a contract a few months ago for building a $5,500 house. These boys, fourteen years or over, made their designs and have done all of the work. It seems to me a great inspiration for the boy because he sees that he is accomplishing things, and that is far better than making up forms and things of that sort.

I don't know that we can say that this Connecticut plant is the only solution of the problem, but it seems to me that they are working along the right lines and I was greatly impressed with the character of the work that they are doing. They are doing a great many interesting things. It is practical, every bit of it.

Another feature that I should have mentioned earlier—any boy fourteen years or older can attend that school. I saw one man there of some twenty-five or twenty-six years. And a great many boys go from the sixth grade into the

school and are doing very good work. It is possible that there should be a little closer affiliation between the school and the municipality in which it is located, but I like the spirit they show. They don't ask the boy if he comes from Bridgeport, or where he comes from. A great many boys come there from the farms outside, and they belong there as well as the boy from the city. It is certainly interesting in the way the plant has worked out and I am very glad to call it to your attention this morning. If any of you can find time to stop off there I am sure you will be very much interested.

J. P. Jackson: May I ask Mr. Rohrer whether, in the large number of young men that he employs, he has noticed any distinct differences in the kind of men they are on account of the different kind of education that they have?

Albert L. Rohrer: I don't know as I can answer that question. A great deal depends on the characteristics of the boy, how industrious he is and how anxious he is to get on. We of course prefer boys—I am speaking now of the apprenticeship work—we prefer boys who have been through the eighth grade. But we have found boys who had dropped out before they were fairly started in the seventh grade and they got along just as well. It all depends on the characteristics.

W. S. Franklin: I would like to ask whether the school is run the year round, or whether they have a vacation in the summer?

Albert L. Rohrer: Fifty-two weeks in the year. And may I say a word more? Mixed up with this, they are doing several other things. They maintain a night school carrying along the same lines so that boys who are working in the city or elsewhere can come into the night school. They also have the continuation idea. A number of the small manufacturers in the city who have apprenticeship boys, but not in sufficient number to maintain a school for them, send their boys a half day each week and they receive instruction in shop work and mechanical work there. You can see that they have a combination there where nothing stands in the way of the boy or man who really wants to improve his condition.

W. S. Franklin: I would like to know whether the Bridgeport school attempts to reproduce the shop equipment in detail of the various industries for which they attempt to train the young man; or do they give the more elementary and fundamental phases of all industrial work? I ask that for a very practical reason. A number of us have been discussing in Bethlehem the question of starting a school of this kind, and the problem we are faced with at once is whether it is justifiable to reproduce at a large expense the machinery equipment in the existing shops, or whether we ought not to try to give the boy a beginning in his apprenticeship work so that he can afterward get the more detailed training in actual shops. I want to know simply, does the Bridgeport school have a complete shop equipment in the metal working industries?

Albert L. Rohrer: Very complete, including an assortment of lathes, milling machines, and one or two planers. Of course a boy fourteen years old has got to begin with fundamentals. But it is worked out in a very practical way. If they take, for instance, a repair job, a boy is sent to the place where the piece of machinery is located and he makes a pencil sketch. He comes back and makes a drawing of the part. Then a pattern is made and when the casting comes in the boy machines it and he is sent out to put the piece in position.

Henry H. Norris: In a recent letter, Mr. Glenn, the superintendent of the Bridgeport Trade School, states that the "day school runs nine hours a day, five days a week, four hours Saturday, fifty-two weeks a year, and that the length of course is 4800 hours, approximately two years for boys." He also states that the manufacturers' association has allowed two years on commercial apprenticeship for graduate machinists, exactly the time spent in school, so that the boys enter the trade of machinist with full credit for the time spent in this school applied to their period of apprenticeship. I also want to call attention to the "Artisan," a monthly publication of this school, entirely the work of the boys of the school. It gives a delightful picture of the school from the standpoint of the student.

J. W. L. Hale: I think it is evident to you that within the last decade the subject of corporation industrial education has become significant. It is a matter generally of the conservation of mental as well as physical resources. As has been well said this morning, when the country's resources become reduced it is necessary to turn more strongly toward development on the mental side. You can cite the example of Germany in this connection. Germany's resources compared with those of the United States, are poor, but particularly in the mechanical line Germany has endeavored to, and is, conserving mental resources. In the United States, within the last few years, considerable attention has been directed toward the subject of physical conservation, and now we are discussing the question of mental conservation. One agency for mental conservation is the corporation school. The railroad school is one which I want to discuss for a few moments.

The functions of this class of school are given in the Report as follows:

"1. To improve the quality of mechanical skill available in shop work.

"2. To make apprenticeship attractive to intelligent boys.

"3. To make it possible for the right kind of boys to rise from the ranks to positions as foremen and master mechanics."

As far as the speaker's experience goes it seem that the third function is perhaps the most important. In order to make the third possible, the second must be carried out. That is, apprenticeship must be made attractive to intelligent boys. In the case of the Pennyslvania Railroad, which has recently taken

up the question of industrial training in shops, in the present stage of the work, it is impossible to hope to recruit the mechanical force in the shops entirely from apprentices. In Altoona alone there are approximately at the present time 12,000 employees of the railroad. The apprentices number approximately three hundred. Therefore, my former statement, I think, is evident. However, it is highly desirable to develop the three hundred for positions of responsibility in connection with the shop management.

The growth of the railroad school in the last five years has been remarkable. There are at least eight representative roads through the Eastern and Middle States which are giving apprentices well organized courses of instruction—I don't like to say theoretical—but in underlying principles and in shop work as well, and they are getting results. The tables which are shown in the Report, given by permission of the Pennsylvania Railroad officials, are made up from data obtained in the spring of last year. However, they represent conditions at the present time. If we refer to these for a moment it might be well to note that the development thus far along the line of railroad schools has been confined to apprentices in mechanical departments, except in the case of the Union Pacific Railroad which is doing a general educational work by correspondence. They have an evening school at Omaha for apprentices, of the Omaha shops only. They are doing a good work generally, but since the instruction is conducted by correspondence it has some disadvantages which are inherent in that method.

So far as the organization is concerned, the roads giving instruction to apprentices in the mechanical department are managed by the motive power officials. Instruction is given in both shop and school and includes elementary subjects from arithmetic to mechanics, and is presented in a severely practical way. The work of these schools is distinctly different from that of a good many other types of school from the fact that we have to change over the courses of the common school for specific trade purposes. This work opens up a new field in changing over from the general into more practical and definite subjects. The preparation of the boys that we get varies all the way from the sixth or seventh grade grammar to high school graduates.

As has been well said, what we have to do, is to give the boys the proper degree of ambition, enthusiasm and interest. There is only one more point for which I will take your time, and that is to repeat the statement I made first, that we must conserve mental as well as physical energy and give attention to development and increase of efficiency on the educational as well as on the mechanical side. It is necessary to develop the human unit as well as the mechanical unit.

W. S. Franklin: I happen to be quite familiar with a recent educational movement in the Pennsylvania Railroad in the telegraph department, which is superintended by

Mr. Johnson, and the work that he is doing illustrates a matter which has been in my mind for a long time and which I had in mind when I asked the question of Mr. Rohrer as to the duplication of existing industrial equipment for educational purposes for schools.

It seems to me, if I may preface what I want to say by a general statement, that one of the greatest problems we have in education at the present time is to make use of industrial and commercial establishments as schools to the extent that they *are* schools, and I think that they are schools to an extent which we scarcely realize. We have been going on for many years, detaching school work from practical work. And I think that one of the most serious faults of our present educational system is its detached character. We place a boy or girl in a seat, at a desk, with a book to study, requiring power of application they have not got and ideas that they have not got to understand. This seems to me to be the most unfortunate thing that can possibly be imagined.

Now, what I want to say is this: if boys of fourteen years and older are able to earn money in industrial establishments by going in there against the law, or on the basis of perjury of their parents, why is it not possible to place them there under the supervision of the public school officer to see that they get a proper variety of work and to see that they work not to exceed a certain maximum number of hours? Why isn't it possible to make use of the industrial value of that youngster at the same time that we are training him?

Now what Mr. Johnson is doing is this: Mr. Johnson's department in the Pennyslvania Railroad is the telegraph system, and his equipment, of course, is spread over the whole United States, pretty nearly; it is a distributed equipment which cannot be made use of for school purposes except it be organized as a part of a correspondence system, and Mr. Johnson is now establishing a correspondence school for all of the employees of this department.

As I said awhile ago a number of us in Bethlehem have been discussing this question and the one thing that stares us in the face is this—what is the use of the town of Bethlehem buying a new lathe when there are about a million lathes in that town already? And what is the use of the town of Bethlehem doing a great many other things in useless duplication of existing devices which are already crying out for somebody to use them? We must study to some extent how to make use of existing commercial and industrial establishments as schools to the extent that they are schools.

And just one other thing I want to say: In order to realize my idea, let us devise, let us plan detached schools for babies, so that by the time our youngsters are fourteen years old they can do something that is commercially worth while in an actual establishment, instead of in detached establishments.

I am very glad to know from what Mr. Rohrer says, that a nine-hour day with six days a week, or nine-hours for five days and five hours on Saturday, is the rule in the Bridgeport school; and that means an approach to real discipline which is good to see.

A. L. Williston: I am somewhat familiar with the plan of the Fitchburg School. It is an adaptation to high-school conditions of the plan which Dean Snyder has worked out for university conditions in the city of Cincinnati. The boys enter the Fitchburg high school on very much the same terms as any other boys enter other high schools. They spend the first year in the high school giving their whole time to the school work inside the school building. During the second, third and fourth years, however, an arrangement is made with local manufacturers in Fitchburg by means of which the boys spend alternate weeks, one week in school and the next week in some shop in the city.

There is an effort made to distribute the boys around in different shops during the different years of their four years' course, so that each boy will get some experience in wood-working, some experience in foundry-work, and a larger amount of experience in machine shop practise. For some boys the plan is working admirably, especially for those who are fortunate in getting into shops where the conditions are such that they have a chance to work on a variety of tools and to get intelligent answers to questions regarding how this work should be done or how that machine should be operated.

Without doubt, there is in all the shops the endeavor to treat the boys as well as possible; and the school authorities endeavor to carefully supervise them in the commercial shops so that all is being done in that direction that can be done. But nevertheless, I think this statement is entirely fair: Many of the persons who provide places in their works for these "part-time" boys find it extremely difficult to so organize their shops as to make it possible for each boy to get the variety of work and the change of occupation that he ought to have for his most rapid advancement. The conditions in some of the shops make it necessary for a boy to do things which he already knows how to do, and to continue to do this week after week, wasting a good deal of his time. In other shops the atmosphere is not stimulating either to the boys' intelligence or his ambition, and he does not learn from the workmen around him the spirit of co-operation.

On the whole, however, I think the plan is working well, and I believe that the boys who are taking the part-time course are getting a far better industrial training than they could get with the facilities in Fitchburg in any other way; but I don't think that it is by any means demonstrated that this is for all places the best way. The State Board of Education in Massachusetts recognizes the Fitchburg plan as one of the ways to give industrial education, but it has also encouraged in other cities, in Worcester, New Bedford and elsewhere, the establishment of schools of very

much the type of the Bridgeport school which Mr. Rohrer described, in which the boys are kept all of the time in an atmosphere that is, I believe, just as honestly industrial as is the atmosphere that the apprentice boy finds in the average commercial shop. This enables the school to keep complete control over the situation at all times, and the boy to be transferred from machine to machine, or from department to department, as is necessary for his best advancement.

The course of school instruction in the part-time school at Fitchburg is modified somewhat from the usual high school course in order to make it better fit the needs of these boys who are spending one-half of their time in commercial shops. This modification or adaptation of the school instruction to make it dovetail in with the shop practise and fit the special needs of these boys, is growing, but as yet it has not been developed as far as I believe the authorities in charge of that school feel is desirable. If further information is desired, I shall be glad to answer any questions which you gentlemen may desire to ask.

W. I. Slichter: The states of Massachusetts, Maine and Wisconsin provide that this arrangement may be carried out and it is carried out in a number of instances, particularly in Massachusetts. In the report of your committee you will find a definition of the "part-time school" and this statement in the body of the recommendations:

"In the opinion of this committee, the feature of the Massachusetts and Wisconsin laws, which causes them to excel those of all other states, is the provision that in order for a vocational school to receive state aid it must receive the state's approval of many of its important features such as; courses, teachers, buildings, methods, time and accounts. This clause is used as an inducement to encourage the local boards to consult with the proper representative of the state board from the beginning of the organization of the school, rather than await the exact period when money is requested of the State. The State board includes an assistant superintendent who has made a special study of the subject of vocational training, and as members of the Board are private citizens representing the points of view of employers and employees."

William McClellan: It was my privilege for several years to be in manual training school work as a teacher, and later to be connected with engineering education in one of our larger institutions. With all due respect to those who favor industrial education, it ought to be recognized that, so far, it has been framed and worked out rather from the standpoint of the corporation than from the standpoint of the individual.

Proof of this has been given this morning. For example, Mr. Stott said that he was forced into it, and yet Mr. Stott has proved that his thought and aim in every respect are philanthropic. The apprentice system has failed and corporations have been driven to take up some other means for getting their industrial workers.

Again, when Mr. Williston spoke this morning of ambition, and the cultivation of it, it occurred to me that the necessary condition to cultivate it and to have it grow and accumulate is that in which there shall be not only an inlet but also an outlet.

The man whom you expect to be an ambitious man should never find himself or be set in a blind alley. I am impressed in this discussion today with the distinction which is apparently made between the so-called vocational school and the so-called professional school. At the beginning we seem to be dividing men arbitrarily between those who must go into vocations and those who must go into professions. This leads me to think that correlation is really what we must strive for.

Those of you who remember Plato's " Republic " recall that a scheme was laid out by him in which men dropped out along the road. As their mental abilities were discovered by the state, they were arbitrarily side-tracked here and there, and there was a gradation of activities until, at the top, was government in its noblest sense.

I have never framed a definition of the word " professional " as applied to professional schools, but it has seemed to me that the difference between a profession and a vocation is that as you deal more with the human element you get into what we designate " professional work." That is the reason today, I think, that the occupations of the clergyman, the lawyer, and the physician are regarded as professions. We hear so many ask why engineering does not stand with the professions, and I believe that the answer is that we have not yet begun to deal sufficiently with the human element.

I find, however, in our professional schools, so-called, that we are turning out four or five classes of men. We turn out the mere operative, the man who for all his life must stand at the drawing board, machine, or instrument and this is as far as he can get. Then we have the engineer business man. He is not an engineer in the true sense. Then we have the genuine engineer who really designs and constructs on original lines. And, finally, we have from the same course of study, a type of man—for which I am really indebted to Professor Bedell for a name—the " industrial physicist " who does not actively get into engineering but who applies science.

Now, gentlemen, these classes are needed and we must arrange for their development. We must start with the boys and correlate all these agencies for education in such a way that men will find themselves by natural selection. We cannot select them at the beginning. We have no business to assume that there is a certain class of vocationalists here and a certain class of professionals there when they are thirteen or fourteen years of age. We must provide means in our system for professional, industrial, vocational, and what not education in proper relation so that the workers will drop into vocations and professions for which they are particularly adapted.

In line with that, let me make one suggestion which I think I have made several times before, and that is, that as an engineer I do wish that, as far as professional and educational interests are concerned, we could get rid of the use of adjectives.

Yesterday President Dunn spoke, I think, of some thirty-four different kinds of engineers and of the fact that when we want to do anything in this country for engineers, we have to get joint committees for pretty nearly every one of the thirty-four organizations. Is it any wonder that we do not make more progress? I wish that the colleges would stop using the adjectives for the mere graduate, or bachelors, and call them graduates in engineering. Later, let them grow into engineers—civil, sanitary, mechanical, electrical, bridge, industrial, and so on.

Professor Diemer: Right in line with what the previous speaker has said I would like to call attention to a charting of industrial education along Plato's line, only modernized, by Dean Pearson of the Tuck School of Finance in Dartmouth College. In a little book entitled "Industrial Education" he has outlined a chart in which the central path shows the continuous flow of the common school education, and he recommends there a branching off on one side or another, particularly the establishment of such systems of education in which a child can be branched off at any stage, we will say, after the seventh or eighth grade, and made to receive certain lines of education which will insure his becoming a better citizen in the line in which he is forced to go.

For instance, we have here the continuation school after the seventh and eighth grade, and we advocate that the common school system should include constantly certain principles of fundamental work, we will say, in science or mechanics, simplifying those terms as will best suit, or manual arts, arts and crafts, which are not intended to be in any sense of the word educational, but general culture. Now we should supplement that common school, Dean Pearson says, by certain systems of education on the one side branching off for the men who have more ability with handicraft, and on the other side for those who have ability in accounting and clerical work. So that we branch off on the seventh or eighth year to provide a system of education which will better them in their lives. Then we must provide for trade schools or for industrial schools which will take the place of high schools which are intended as a system flowing into the college. Then he advocates in the college also, a certain differentiated technical college course. He would have this college course divided, each side containing a predominancy of management, but the one side of a predominancy of the scientific technique and the other of instruction in accounting and financial technique. I simply call attention to that suggestion of Dean Pearson as carrying out a little further the idea of the previous speaker.

Comfort A. Adams: I wish to endorse most heartily what Mr. McClellan has said, since it strikes at the very root of the prob-

lem. This problem is not solved when we have provided industrial education for those who, by accident of birth, cannot afford anything else, although that is doubtless a step in the right direction; the problem is not solved when we say to at least 80 per cent of our boys—" You may attain to the position of high grade mechanic but may never gain admission to the professional fields no matter how much better your native talents may be adapted to professional work."

At the same time, we are forcing through our technical professional schools many young men who are there chiefly because their parents can afford to give them the higher education and not because they are able to profit by it in any marked degree. I am not forgetting the numerous scholarships, evening schools, and other aids to bright boys of slender purse, but I think you will find on closer scrutiny that the beneficiaries of these various aids come in large part from the financial upper 10, or at outside, 20 per cent of the population. Neither am I overlooking the very exceptional men who cannot be kept down by any lack of opportunity; they make their own opportunities. If we were to base our educational system solely on the needs of this exceedingly small group, our problem would disappear.

We thus have a social order in which education beyond the rudiments is so restricted that we are practically wasting a large part of our raw material, in so far as the assorting of the men for the various occupations and professions is based largely upon accident of birth rather than upon real fitness; upon the extent of the parent's pocketbook rather than that of the child's intellect.

The only factor which should control the opportunity for an education is the relative ability to profit by it, and while this may seem a millenial ideal to many, our talk of " equal opportunity " is hypocritical until we have definitely set ourselves the task of realizing that ideal.

We talk much of efficiency in our engineering work, but we are apt to overlook these very vital considerations which affect so tremendously the efficiency of the whole social organism of which we, as individuals, are very small parts.

I realize fully how far such questions reach, and that they involve the consideration of many subjects and problems neither primarily educational nor engineering in their nature, but they are problems which we as citizens must face, and many of which would be vastly simplified by the application of engineering methods.

Therefore, while we are lending our cordial assistance to the promotion of the numerous extensions of our educational system, let us not lose sight of the ideal of " equal opportunity "; let us work towards that ideal, first, as " citizens of no mean country " and second, as members of no mean profession.

F. C. Caldwell: I am glad to say that in Ohio we are making a good start along this line of industrial education. Besides the general application of manual training to the

grammar schools, we have manual training high schools in the larger towns and in Columbus, at least, they are also experimenting with the alternate week cooperative plan in connection with manufacturing companies. I agree with Professor Williston that this is something which should be regarded as an experiment. It is certainly a good thing for some cases and always much better than nothing. But that it is better in the case where a man is able to put all his time into his school work is by no means demonstrated.

This educational attitude, which the employers of labor forming the manufacturing companies are coming to adopt toward their employees, is exceedingly promising in one direction which has not been mentioned. When the personal employer was superseded by the corporation with its officers there was a great loss in the personal and friendly relationship with the employee. I suppose a good many here, like myself, have been through the shops and they probably found, unless under unusually favorable conditions, that the employees felt they were simply parts of a big machine, that their personality was of no consequence; that the corporation employed them to do a job and that it was a matter of absolute indifference to the employer whether they stayed or went, whether they advanced or not. That there has often been some justification for this feeling cannot be questioned. It seems to me that what you might call the "educational attitude" of the corporation toward the employee may do something to fill the place of the old friendly relationship between the personal employer and the employee.

One other point that one of the recent speakers brought out ought to be emphasized, and that is, that whatever we do in the way of industrial education for the masses should always have in view the possibility of carrying a man further, of giving him the very best education that any one can have. I do not like the idea that when a man selects the manual training high school or vocational school, he is thereby shunted off from the natural course of advancement into the university. We must find some way by which a man who comes to the vocational school and thereby develops and shows the qualities which will fit him for a position as an engineer should have the opportunity to go right on up to the top.

M. J. McGowan, Jr: I would like to ask a question with reference to the relation of the engineering society to the state boards of education in the different states of the United States. Does this society coöperate in every state with the state board of education, to teach particularly the line of electricity? I ask it for this reason. In the state where I come from, New Jersey, the doctors are interested in the advancement of instruction in their line, the agriculturist is the same way, and all the different professions have colleges which teach their particular work. But I have never heard of anybody being interested through the state board of education to take up the technical courses in the schools of the state as to this line. Now having been connected with

the state government, I took great interest in watching the different schools, the different societies and professions which are interested, but at no time in the state of New Jersey have I seen anybody in the electrical line interested to see that the scholar or student should get the preliminary education which would bring him in touch with this particular line or profession. I think this is a very important point and I think this society, in this joint session, should arrange, in all states, committees who would wait on the state boards of education and show them that the electrical field today is one of the greatest and most promising of any profession that has ever been known. In the city from which I come, Newark, New Jersey, I have installed in one school a switchboard apparatus, for technical training in the electrical field. It was the first time it had ever been done in this twentieth century. That is due to lack of encouragement to the state board to show that this particular line needs taking care of. You will notice that all these technical schools are situated nearby the different electrical industries. That shows, in my mind, that those industries are greatly interested in the particular schools for their own convenience, for which I do not blame any man or any corporation. They further their own interests. We must try to eliminate if we possibly can any stated line of study being taught or the following of any particular line of material or peculiar workmanship. Let the teacher be interested generally and go through it all from a to z. Don't lay any stress on any company's manufacture or any school. And I trust that in this way we shall undertake to cooperate with the heads of education in the different states. Go to the governor and ask him if he won't appoint some representative from the engineering society or from this joint convention to attend to that matter, and by doing that you will put the responsibility for the teaching of electrical science on the public schools of the different states up to the A. I. E. E. to see that the teaching will be right.

W. G. Raymond: The time has almost arrived when we shall have to ask Professor Jackson to close the discussion, but the chair cannot forego this opportunity of relieving his mind of something which, perhaps, you will consider a heresy. You have been discussing principally this morning the details of industrial education, and sometimes it is necessary to plan the details before we plan the general structure, but it is always necessary to provide the means before the general structure can be built. I do not know whether you all realize it, although you all doubtless know, that as far back as 1862, a plan was outlined and provision was made by the Federal Congress for putting us in a position that we are not now in. This committee says that we rank behind European nations in this matter of industrial education, but if it had not been that the funds derived from the act of 1862 have been almost universally misapplied this country would not now be in that position. It makes no difference whether the

colleges of mechanic arts established under that act were separate institutions or combined with state universities, the money has never been used for the development of mechanic arts. I think without exception there has been no school of mechanic arts created in any state under that act which provided distinctly for schools of agriculture and schools of mechanic arts. Dean Jackson will now close.

J. P. Jackson: I suppose from the remarks made by Professor Raymond that he is not familiar with the basis of organization of the Land Grant Colleges. The measure passed by Congress in 1862, in regard to the establishment of these useful institutions, is as follows:

"The leading object shall be, without excluding other scientific and classical studies, and including military tactics, to teach such branches of learning as are related to agriculture and the mechanic arts, in such a manner as the Legislatures of the States may prescribe, in order to promote the liberal and practical education of the industrial classes in the several pursuits and professions of life." This includes everything, I believe, that is being taught by the great bulk of our State and United States supported or, to use the official title, Land Grant institutions. These institutions have always been alive and vigorous, have been leaders of educational thought along the applications of science, and have proven of prime usefulness to the nation.

W. G. Raymond: I agree with you.

J. P. Jackson: If that is the case, I need say no more on that subject. I think there is a great deal in what Mr. McGowan said; his plea is similar to that contained in this morning's report by the educational committee. It is a necessary preliminary to have such discussion as we have had among engineers, in order to arouse sufficient interest to do what Mr. McGowan has asked. His plea was made with reference to a specific act. Let me broaden it. If each one of the eleven thousand members of these two societies will use his influence in his local community, to get in touch with the school authorities,—get himself appointed to some committee or otherwise place himself where he can be of service—he can, or the eleven thousand members can, do much to raise the efficiency, improve the happiness, and remove the discontent that seems to be growing among the hand laborers of this nation. If the TRANSACTIONS containing the discussion of this morning persuade only five hundred of the eleven thousand members scattered out over the country, who are now inactive in educational matters, to engage in the movement under discussion, this meeting will have been well worth while. It will have been the incentive to cause men of intelligence in our industries to become more active in doing what Mr. McGowan suggests; that is, going actively and practically into the machinery of the state to help develop our people in a proper manner. I say to the electrical convention here assembled and to the American Institute as a whole, that I believe there is no other way in which the electrical industries can be so rapidly improved, as by prop-

erly solving this very question, which we are discussing this morning, with reference to producing the greatest efficiency in our young people. There is apparently no specific answer required to any of the other discussions of this morning, as the papers presented were really not under discussion, but rather the general problem.

Harry Barker (communicated after adjournment): Professor Williston has pointed out the vital necessity of securing the proper boys for the various vocational school courses and the difficulty that such schools have in selecting from the candidates presented.

It ought not to be necessary for the vocational school instructors to have to step out of their true sphere to do this work. They cannot hope to have the available time or the data and information at hand to make the wisest selections. They need not perform this unwilling function if the cooperation which Mr. McClellan and others have spoken of, is secured with the present public school systems. The organization of vocational guidance based on the boy's manifest aptitude, on his environment and heredity, and based somewhat on a psychological study also, has advanced to such a stage that it is a necessary link between the existing graded schools and vocational courses. The work has risen to its highest development, so far, in vocational bureas such as found in Boston. Trained and experienced men now find out what work or study the various pupils seem best fitted for and how far they seem capable of progressing; the counselors advise what paths pupils may well follow and what ends they should aspire to, and finally keep track of them for a greater or less number of years, to see that they do not stagnate either from inherent tendency or outside influence.

While this work has been carried out to the greatest extent with bureau organization, yet there is much of the work within the ability of the grammar and high-school teachers and even such modest beginnings are better than waiting for the organization of a completely equipped bureau. Indeed the largest success will be greatly hastened by an early start. This function, moreover, is one very properly tied in with the work of the local superintendent of schools, acting as the general adviser of other teachers who are striving to make some safe beginnings at vocational guidance, and as the collector of information about local industries and opportunities.

There is not time here to describe the work in detail; it can be studied however, by those interested. In reaching out for cooperation with state boards and local educational authorities, this is a chance for immediate effort and practical benefits, not to be neglected. Where there is a vocational school, it is a necessity for efficient work; where there are no vocational courses, it is of the greatest possible good in preventing misfits. Once undertaken, it will lead logically to such vocational courses as are best suited to the local situation.

DISCUSSION ON "SIMPLIFICATION OF ELECTROTHERMAL CALCULATIONS; THE WATT AND THERMAL OHM" (HERING), BOSTON, MASS., JUNE 25, 1912. (SEE PROCEEDINGS FOR JUNE, 1912).

(*Subject to final revision for the Transactions.*)

H. B. Gale: I think the new unit proposed in this paper is a very practicable and useful one, and I hope it will become adopted as one of the new tools of the profession. I have spent a great deal of my time in the last few years in making calculations on electric heating, and have found it necessary to work out a table of constants for calculating watts transmitted by different substances per degree difference of temperature, and I am very much obliged to Dr. Hering for giving me a name for the constants of my table.

Carl Hering: Dr. Kennelly suggested the name for that unit.

H. B. Gale: I am grateful for the name anyway. But it does seem to me that the name thermal ohm is open to objection, because it is liable to be confused with the electric ohm. These will be abbreviated ultimately, and it occurred to me that it could be called a "thermohm," and then it would not be confused with the other. Or you could reduce it to "therm." I believe that the unit is one that is destined to be exceedingly useful and to simplify our work very greatly.

Alfred H. Cowles: It seems to me that the adoption of such a unit would lead us around a great circular path, with the ultimate discovery that we do not come back to the beginning point. We start with old work done about a century ago, from which there was defined the dyne of force, the electrostatic units, and the centigrade degree of temperature. Later, we passed to electrodynamics, with the evolution of its derived set of units dependent for their magnitude upon those units that had formerly been determined and the velocity of light, barring the cutting down of the electromagnetic unit of rate of flow ten-fold in order to secure a more convenient unit of rate of flow, the ampere.

In the study of heat, the units have been developed independently, all upon the c.g.s. system with the exception of the unit (T) for the rise in temperature or difference in temperature potential. This latter is arbitrary. The watt as a measure of rate of energy flow per second, per second, is directly derived and dependent upon the magnitudes of the volt and ampere. If we use it to express a rate of flow of energy, in the form of heat conducted per second, per second, it would seem to me that we would have to have also a thermic volt to go with the proposed thermic ohm, and there should be some natural relation between the thermic volt and the electric volt, and also some natural relation between the thermic ohm and the electric ohm, but this would imply something to correspond in its nature to the ampere. But the watt is a product of a volt times an ampere, while an ampere is a unit by itself expressing a rate of flow of one coulomb per second per second.

Here, in the failure of a watt and an ampere to correspond in their natures, we find that in our circular path we have not returned to the point of beginning. The electric ohm is that resistance which will permit one ampere to flow with a fall of potential of one volt between two terminals. We may note that the absolute nature of this resistance or its mechanics is not clear to one's mental conception, but *R* multiplied by amperes squared times seconds gives units of energy, watts or joules. If we evolve a law of heat conduction that is analogous to Ohm's law of electric conduction, it seems apparent, nevertheless, that we cannot use the watt as a rate of energy flow if we are to introduce a thermic volt, and also a thermic ohm.

We can, however, call one degree centigrade a thermic volt, which gives us a thermic ohm arbitrary in its nature, very much as the degree centigrade is, for it would depend upon the latter. Maintaining the watt as it must be, a constant, we can change the magnitude of the thermic volt to any amount, with a corresponding change occurring in the magnitude of the thermic ohm. For instance, were we to make the thermic volt 96,000 deg. cent. to correspond numerically to the electrochemical equivalent in electrolysis, and call it unity, then one watt equals one thermic volt having as its equivalent 96,000 deg. cent. of temperature. Now making the intangible thermic ohm 96,000 times larger in magnitude, as proposed by Dr. Hering, we would have two natural relationships between electricity and heat introduced into the proposed formula, thus making 96,000 a unity—it would be a thermic volt. We already have the watt per second, per second, as a rate of flow of energy, and recurring to Ohm's law in its new form, we have one watt of energy will flow per second when a difference of potential of one thermic unit exists between two sides of a wall whose ends, top and bottom and sides are perfectly insulated, having a resistance of one thermic ohm. In this form the numerical relations between a new thermic ohm and the electric ohm may be made to mean something valuable. A natural numerical relation between the volt unit as a measure of difference of electric potential and the temperature, centigrade degree, unit as a measure of difference of heat potential, can then be derived.

Carl Hering: I think if Mr. Cowles will examine these relations more carefully he will find that he is mistaken in some of his remarks. In the flow of heat the unit he calls "thermic volt" already exists in the degree of temperature. When the flow of heat is expressed in watts, it has its analogy in an electric circuit in the form of a flow in amperes. Instead of this leading to complications it seems to me to lead to simplification.

Alfred H. Cowles: I am pleased to hear that stated, for, in a paper read before the Electrochemical Society at the first Niagara Falls meeting, I pointed out the very fact that differences of heat potential in a body were perfectly analogous to differences of electric potential, and if one could introduce a unit

analogous to the ampere, one could study the heat flow in the same manner as flow of electricity is now studied.

I think " watt " as used by Mr. Hering expresses a quantity of energy rather than a rate of flow or flux of energy. A new name should be supplied bearing the same relation to a watt that an ampere bears to a coulomb. In the latter portion of my remarks I described a thermic volt whose magnitude is a multiple of the degree centigrade. This discloses a means of establishing those units, without making the thermic ohm dependent for its magnitude on the arbitrary value of the degree centigrade, amd maintaining them within the c.g.s. system.

Carl Hering: Mr. Gale's acknowledgment of the usefulness of the thermal ohm agrees with statements made to me by others who have had to make calculations of heat flows. The fact that those who have used this unit find it useful, is the best kind of an endorsement.

The names " thermohm " and " therm " which he suggests may perhaps be considered better by some, as also the term " thom." But in the writer's opinion too much abbreviation sometimes involves a loss of time rather than a gain; this is apt to be the case when the longer name is self-explanatory and the shorter one requires a definition which one must look up. The writer favors self-explanatory names.

Concerning Mr. Cowles's remarks, I think he will find some of his criticisms answered in the paper itself. The generally used heat units are not based on the c. g. s. system, as he supposes; the unit of heat in the c. g. s. system is the erg, while in the independent system it is the calorie. He is mistaken in saying that the watt is " the rate of energy flow per second, per second;" the watt is a unit of power which is energy per second, and therefore is a true measure of a flow of energy, or in general, of a transmission of energy from one place to another. Nor is a rate of flow of energy " heat conducted per second, per second." There seems to be no " natural relation " between what he calls the thermic volt and the electric volt, nor between the thermal ohm and the electric ohm; they are merely analogous; they are totally different physical quantities, hence there can be no equivalent between them any more than there could be between a meter and a kilogram; the two latter are connected by the fact that a cubic decimeter of water weighs a kilogram, and it might be possible that some such connection might be found between the thermal and their analogous electric units.

An ampere is not " one coulomb per second, per second," but simply a " coulomb per second." There is no reason why the watt and ampere should " correspond in their natures;" they are simply analogous when the watt is used in its broader sense of a power unit. We ought to dismiss from our minds the idea that the watt is an electrical unit, which it is not; it is the decimal multiple of the c.g.s. unit of power and therefore measures power in any form, whether electrical, thermal, mechanical, chemical,

luminous, acoustical, etc. Mr. Cowles uses watts and joules indiscriminately as "units of energy;" this is incorrect, joules are measures of energy and watts are measures of power, that is, rate of energy. He is also wrong in stating that resistance "multiplied by amperes squared, times seconds," gives watts; it gives joules. A "watt per second, per second," is not "a rate of flow of energy." Many unfortunate errors have arisen in this confusion between power and energy, and it is often found today in the expression "cost of a kilowatt," when a kilowatt-hour or kilowatt-year is meant; a cost of power is meaningless unless the time in which it is used is also given.

As I have already said, I think Mr. Cowles's suggestion of a "thermic volt" equal to 96,000 centigrade degrees would lead to complication rather than to simplification, and it would increase our already too numerous conversion factors; the writer has urged a reduction of these time-robbing numbers rather than increasing them.

Mr. Cowles is mistaken when he thinks that the watt, as used by me in the paper, expresses "a quantity of energy;" it does not, it expresses a time rate of energy. The watt, as used for a flow of heat, already bears the same relation to the corresponding unit of heat in this same system (namely the joule), as the ampere bears to the coulomb, hence his suggestion to supply a new name is not necessary.

I cannot endorse Mr. Cowles's suggestions and I have no reason to change my belief that great simplification would result in our calculations if we made all our units decimal multiples of the c.g.s. units, as the electrical units are, and that we should tend to go in that direction whenever there is an opportunity presented such as the introduction of a new unit where none has existed before, as was the case with the thermal ohm.

Discussion on "Does it Pay the Average Coal Mine to Purchase Central Station Power?" (Bright), Pittsburgh, Pa., April 27, 1912. (See Proceedings for May, 1912).

(Subject to final revision for the Transactions.)

E. D. Dreyfus: We are indebted to Mr. Bright for having added another interesting chapter on the subject of electric drive and the use of central station power and in taking the opportunity of opening the discussion I wish to make note of some important facts which should be kept in mind in connection with the quotation of rates for power purposes. Mr. Bright has been obliged to confine his comparisons to specific cases only and personally I feel that his deductions are very instructive and valuable.

But in regard to the cost of power generally, a note of warning should be sounded, as a wide variation is liable to be encountered depending upon local conditions. To exhibit the extent of possible fluctuations in cost, I have assumed a number of changes in conditions at random and obtained the following variations:

(1) With the size of the unit sextupled, the cost per kw-hr. would be reduced from 2.05 cents per kw-hr. to $1\frac{1}{8}$ cents per kw-hr. total, all other conditions remaining the same.

(2) Now, with the plant quadrupled by adding, say three additional units of the same capacity, the cost would be lowered from 2.05 cents to only $1\frac{1}{3}$ cents per kw-hr. total.

(3) If the load factor was improved from 25 per cent to 75 per cent, (high percentage taken for the purpose of illustration), the cost would be decreased from 2.05 cents to somewhat less than a cent per kw-hr.

(4) On the other hand, reducing the size one-half, the cost would rise from 2.05 cents to $2\frac{3}{4}$ cents.

The basic conditions are a 300-kw. condensing steam unit, $1 coal and average operating economics.

The above facts apply with the same force to the independent plant and are likely to be more serious in the case of light load factor.

Geo. R. Wood: There is one point which has not been brought out clearly, which is that the saving in cost of power, though important, is less than the saving on other items in the cost of coal per ton. I think Mr. Bright's figures show a saving in power cost of $1\frac{1}{2}$ cents per ton of coal produced. My experience has shown savings as high as five times this amount due to these other items, chiefly in labor and repairs.

The items on the cost sheet affected by higher and more uniform voltage underground are: (A) overhead, including interest and depreciation on investment, (B) labor, including operating and repair men, (C) supplies. (A) is reduced on account of increased production with the same equipment, which in some cases amounts to 30 or 40 per cent; (B) is less for the same reason, and also because repairs and upkeep are substantially

reduced; (C) is also reduced on account of fewer burnouts and increased efficiency of apparatus.

As a concrete example I might quote a large mining concern, which four years ago was operating 10 power plants, averaging 400 kw. each, at 550 volts direct current. The power distribution, over a very large area, was very good, better than the average mining plant. About 40 locomotive armatures per month were repaired in the shop. A central power plant of 2500 kw. was installed, with seven substations located near the centers of power consumption. The saving in power cost was almost four cents per ton, or about one cent per kw-hr. produced, while the total saving was nearly ten cents per ton, or in other words the saving incidental to better underground voltage was approximately 150 per cent of that due to saving in cost of power alone. There are now not more than four locomotive armatures shopped per month, out of 168 in service.

H. M. Gassman: I am particularly interested in this paper, as I had occasion to solve the same problem, occupying the dual position of being interested in central power generation and distribution as well as looking after a large number of isolated stations and substations in connection with coal mines. As far as the central station is concerned the load is desirable, being largely a day load, and the fluctuating nature of the load of one station is not objectionable provided a sufficient number of stations can be secured.

I wish, however, to take exception to some of the items in the summary; first, "lower cost of operation." This I assume refers to the cost per kw-hr. delivered at the switchboard; if not, then there is some question about it, as the isolated station will have to pay for the loss in transformation and also ultimately for the transmission loss. Second, "worry and care of power plant removed." I do not think that it is of great importance, unless the power companies contract to deliver the power to the switchboard. Then, in that case, we still have to contend with an organization to take care of the power consuming apparatus. In item 7 Mr. Bright says: "Increase of production on account of increase of efficiency, due to ample power at all times." The power available is limited by the transforming capacity of the apparatus installed.

There is one point I wish to call attention to, in the tabulated data, where the mention is made of "500 tons of coal at 50 cents per ton." In figuring the saving, you can only count on saving the profit on the coal which if not burned under the boilers might be disposed of at a profit. This will make a slight difference in the figures, but in general it does not affect the discussion.

In addition I would like to point out some of the disadvantages of the central station power supply. One of the factors that has been omitted in this discussion is that of the transmission line. This is objectionable not only because it introduces a new factor of line loss and regulation that is not present in the

usual isolated station, but because of the danger of interruptions of the service seriously crippling the output. We have to consider more than the actual cost of the power; *viz.*, the loss of profits, that is the loss of product. As an illustration of this I will refer to Table V. At a rate of saving of $0.0125 per kw-hr. the saving is estimated to be $2,375.00 per year. Let us figure that back and find what that is equivalent to in tons output. Assuming say 30 cents profit on a ton, this represents the profit on 8000 tons, or at the rate of production suggested by the author, this would be equivalent to seven days' output. If power is brought from a distance, the interruptions of power at the substation might very easily amount to seven days in the aggregate per annum, if delays and disorganization due to short interruptions are considered. The self-contained generating station is the only thing a steel man will consider. In fact, wherever any important output is at stake, the question of control of the power supply will have to be carefully weighed.

Considering all the advantages and disadvantages, I would favor in the case of old mines installing supplementary power, purchasing it either from central stations or from other sources, and retaining the old equipment, largely for the reason that the salvage obtained from the old equipment is very small and not sufficient to warrant disposing of it in view of its value as a spare in case of some serious interruption of the purchased power. It also would be an advantage in case of emergency, such as increased demands for power during the wet season. I consider the advantage of supplementing the old equipment as far superior to any attempt to abandon it. As far as a new mine is concerned, it is a very much larger question to solve, and it would be foolish to make any general statements as to whether it would be better to purchase central station power or establish generating stations for any particular mine without full knowledge of local conditions.

E. T. Penrose: In regard to the central station purchasing power, or the centralization of power, I have been on both sides, purchasing and selling, and I have installed power in about sixty mines. In the first place, consider the matter of the transmission line. If we refer to Mr. Steinmetz's paper, I think, in the March issue of the PROCEEDINGS, his statement is that there should be no interruption, and there is no reason for any interruptions except from faulty construction. I have found that all interruptions were caused by faulty construction.

As to the saving to the mine, particularly as mentioned in this paper, to a group of mines, it is very questionable whether the purchasing of power from a lighting company, or what is known as the central station, would necessarily be a saving over the installation of a central plant to supply the various mines in the district; the mine company in that case taking the loss of transmission, upkeep, etc. In my opinion, ten or twelve mines in a given territory would be of sufficient size to almost, if not

quite, compete with a central station power plant, as the cost per kw-hr. is absolutely dependent on the load factor, and it is a question if the centralization of the power plant for the mines would not give as high or a higher load factor than is obtained by the central station with the present methods of making rates.

The great advantage I have had in installing central power in the mines has been due to the fact that the small mines do not have the proper engineering ability, and therefore do not run their equipment in the best possible way. Burning out of armatures, which was mentioned, was overcome, not from the fact that they had central station power, but from the fact that substations were installed and high voltage furnished to the mines. Therefore, it was a mechanical engineering proposition, rather than the saving in the purchasing of electric power. However, for the last ten years, I have been strongly recommending the purchase by the coal mines of central station power, when a rate can be obtained from the central station which would be a saving. This rate in many central stations in the coal mining districts is hard to obtain, owing to the fact that it must of necessity be much lower than the average cost of current as produced by the central station. However, the central stations have their maximum load, varying from two to four hours a night, the four hours being in the winter time. During that period they would have their highest load, and owing to the larger development in recent years of power business in the central stations they have got so that some of them run up to 50 per cent load factor. The coal companies could have an average load that will be very close to the maximum for eight hours of the twenty-four during the working period, which would, of course, bring their load factor to about 30 per cent, so that in many cases the coal mine will have a better load factor than the central station.

However, it is the business of the central station to sell power and it is hardly the province of coal operators to do this. The main thing which is against the centralization of the coal properties plant is usually the lack of water for condensing and for boiler purposes. To show the inefficiency of the average coal plant, they will use anywhere from 15 to 35 lb. of coal per kw-hr. That may sound a little high, but it is so. The electric light plant should, with a given load factor, run with a large plant as low as three to four lb. of coal per kw-hr., and possibly lower than that with good coal.

Therefore it is a case of whether the coal companies shall get together and centralize their own power business, or whether they shall allow the central station to centralize their power. I am in favor of letting the power company take charge of this centralization, provided they would give the coal company proper rates.

H. M. Gassman: I think some of the previous speakers misunderstood my remarks. I do not wish to appear to be unfavor-

able to the central station supply for coal mines, but think that the advantages and disadvantages should be presented impartially and conditions in other than the Pittsburgh district be considered.

My statement that the interruptions of supply from central station should be considered in making a decision is based upon experience in a locality where conditions are not so favorable as in the vicinity of Pittsburgh. It is not my intention to call particular attention to the interruptions resulting from trouble in central power station but rather to the interruptions of the service due to line troubles and voltage disturbances which would result in shutting down synchronous transforming apparatus. The service supplied through country that is less developed and more exposed to lightning troubles than the Pittsburgh district cannot be as good as where the conditions are more favorable. This is particularly true on systems with a single station and where the lines do not form a part of a large network.

Furthermore, my reference to the interruptions of service pertains to the broader phase of the subject, namely the actual delay encountered in the mine by power being shut off even for periods as short as that required to start up the transforming apparatus after being shut down by even a momentary line disturbance. A loss of seven days total during a year on this basis is not a serious reflection on the central station power supply. Granted, however, that it is somewhat high, the figures I mentioned were not intended to be exact but for the purpose of illustration, the same as the figures given by the writer of the paper under discussion.

Wilfred Sykes: I was rather surprised at the statement regarding the dangers of interruption, and I will say that in a large power plant with which I am acquainted, which supplies approximately 75 per cent of the industries of two counties, all kinds of loads, over long lines, the percentage of the time it was ready to supply power was 99.98 per cent over a year; that is, there was only 2/100 per cent of the time when it was not ready to supply power to all the customers. A certain portion of the time the customers knew they could not get the power, due to the changing of poles and because of other changes in the line, and the total time during which the power was off altogether was twenty minutes out of 8760 hrs.

The point has been brought up as to the removal of the worry incident to a power plant. I do not think anybody who has had anything to do with mining work will doubt that there is much less worry involved in looking after motor-generator sets than in looking after an isolated generating station; in fact, a great many of the operators will tell you that they are quite willing to pay an appreciable amount if they could have this worry off their minds. They complain all the time about the power plant giving trouble. I think the importance of this question would be appreciated by anybody when you consider the increasing number of central

stations that are being erected simply to supply power to mines. There are now in the course of erection quite a number of large plants, some to utilize water power and others are steam plants.

I do not think Mr. Bright brought out clearly enough in his paper that these figures, although of course only applying to a particular case and used for illustration, are based upon a great many investigations, and by some mysterious means he has managed to get the coal operators to open their books to him. I do not know how he did it, but he did it, and found out what their costs were, and consequently he has been able to obtain a great many data on which this paper has been based.

The question of putting in a central power plant for a group of mines is very often raised as a question of finance. I know of a number of cases in which the operators are quite willing to pay as much for central station power as they could generate that power at themselves, for this reason: Suppose they had to spend $300,000 or $400,000 for a central station plant, it will enable them to use that $300,000 or $400,000 in exploiting their regular business and that is, naturally, a very important thing, and they would rather enlarge their mines, spending that money in increasing their output, than put it into a central power plant just for the sake of running their mines.

W. N. Ryerson: There is one other point I do not think has been brought out in regard to this discussion of supplying central station power to diversified industries, and particularly a number of mines that may be within easy distributing distance of one another. That is the ability to operate a part of the equipment without the heavy expense necessary to operate localized plants; in other words, if you have a transformer station, it requires little or no attendance, and if for any reason some of the mines should shut down you can operate the remaining ones at very much lower cost than would be the case if you had to have a practically full crew operating your central power plant.

Then there is another question in regard to the reliability of service from central stations. A pretty good test of that is the requirements of the fire underwriters in regard to the use of electric fire pumps. If you comply with their requirements, and apply that test to your service and pass the inspection successfully, I think you can safely say that the service is reliable.

H. N. Müller: What are the interruptions on local plants as compared to unavoidable interruptions on energy delivered by transmission lines?

How is the figure of 18 days per month obtained for average mine working? Does this include two shifts a day, and shutdowns due to strikes, car shortage, etc., and what would be the effect of the same on say, a five-year average month? What is the value of flexibility of central station energy in obtaining greater capacity in a short time?

What percentage of voltage regulation on the secondary of the transformer is permissible in this work; and what is the proper factor of this load?

Graham Bright: Mr. Dreyfus has brought out certain conditions which may be met in a mine, but conditions at different mines vary so widely that it is impossible to lay down a set of rules to suit all conditions.

Mr. Dreyfus gave some interesting figures in regard to costs of operation at various load factors. He carries the load factor up to 75 per cent, which is far beyond anything that can be obtained at the average mine. He also bases some of his figures on the assumption of good management. In actual operation we seldom get good management in regard to the power supply, since those in charge wish to spend most of their time in mining and shipping coal, and the power plant is left largely to take care of itself until a breakdown occurs and then every person available comes in and works until the trouble is corrected.

I think Mr. Wood brought out very nicely the fact that even with the same cost or greater, it pays a mine operator to purchase central station power. Mr. Wood has been connected with mining work for a number of years and his opinion on this subject should carry great weight.

In regard to Mr. Gassman's remarks about there not being much in the " worry and care " being removed, I think that no person will question the statement that the " worry and care " of a substation operating from synchronous converter or motor-generator sets, is not to be compared in any way with the " worry and care " which exists with the average mining plant with boilers, engines and piping in the condition that they are usually found in. These plants as a rule are unable to carry overloads of any appreciable amounts, while a modern substation will take care of overloads up to 100 per cent with no trouble. Mr. Gassman mentions the fact that the central station power need be off the line only seven days in a year to wipe out the saving which has been shown. I believe that a large power company which has power off the line for seven days in one year would be considered very inefficient, and you will find that most of the larger power companies would consider this an extremely bad record.

As Mr. Sykes brought out, the figures given in my paper are not theoretical, but are really based on actual facts obtained from a great many mines which had been investigated during the last few months.

Mr. Mueller has asked a question in regard to the power factor and voltage regulation of the power system. A fairly good power factor is generally obtained by taking the supply of direct current for the mines through synchronous converters or synchronous motor-generator sets. These machines can be set for a leading power factor and will tend to compensate for the induction motors which are used for driving the fans and pumps. The question of voltage regulation does not come up very frequently since the mine operator as a rule is satisfied if he gets plenty of power at a fairly steady voltage. The lighting about a mine is of such a nature that close voltage regulation is not usually insisted upon.

Discussion on "Ozone: Its Properties and Commercial Production" (Franklin), Schenectady, N. Y., May 17, 1912. (See Proceedings for May, 1912).

(Subject to final revision for the Transactions.)

C. E. Skinner: From the mass of data already accumulated, there can be no doubt whatever as to the efficacy of ozone as a means of purifying drinking water. One of the Pittsburgh hospitals has an ozone plant installed, and the ozone is used not only for the purification of drinking water, but also for the disinfecting of the rooms and wards. Information in regard to this plant and from other sources has been such as to lead me to question whether there may not be harmful results from the use of ozone, as well as beneficial results. Shortly after the plant was installed in this hospital, one of the physicians experimenting with the ozone received the full strength of the ozone from the outlet tube, and was immediately rendered unconscious, and I believe there was some difficulty in reviving him, but so far as I was able to learn, no permanent injury resulted.

In another instance I was told that in working with ozone in connection with some therapeutic experiments, extreme nausea sometimes followed the work when the experimenter had been in the room with only a relatively small concentration of ozone for some length of time. I would therefore like to ask Dr. Franklin whether or not the strongly concentrated ozone, as in the first case, or smaller amounts as generated by an ozonator in a small room, for example, might not be injurious to persons compelled to breathe the air carrying this ozone.

Mathew O. Troy: As Dr. Franklin has indicated, the production and application of ozone has been developed to a high degree in Europe and abroad generally. Looking at the commercial aspect, I understand that the sale of ozonizing devices in Europe last year amounted to $7,000,000. It is not, therefore, a new subject. De la Coux has written a volume of 475 pages, covering in great detail the application of ozone in therapeutics, and much has been written in the scientific journals concerning its application to the industrial arts and the sterilization of water and air.

Ozonation received an impetus in this country a few years ago when several companies were organized for promoting the application of ozone to the purification of city water supplies. These companies failed from one cause or another, but it was probably not due to any defects in the general scheme of such applications, as the process has been made a commercial and practical success in many of the European cities. It is my belief that some company will again take it up in America and make a success of it.

The production of ozone by electrical means has superseded all other processes. It therefore becomes a problem for the electrical engineer and it is proper, therefore, that the paper which has just been read should have been presented before the

American Institute of Electrical Engineers, and I hope we may have more papers of an even broader scope presented in the near future.

What we need in America today is an abstract study by engineering bodies of the facts pertaining to ozone. It needs to be investigated by the electrical, sanitary, and ventilating engineers, by the medical fraternity in general and, in fact, by all of the engineering and scientific bodies which cover any of the diversified fields in which ozone finds an application.

Until recently the sterilization of air by ozone has been given little consideration in America, except on the basis of patent medicine quackery. There were a few devices on the market, poorly designed, not backed up by scientific investigation and exploited very much in the same manner as a patent medicine. The work was not undertaken in such a way as to gain the support of the medical fraternity, nor to promote thorough investigation or an accurate compilation of facts. Reputable manufacturers in America are now trying to give ozone the status it deserves and place it on the high plane it occupies abroad. The applications are numerous, but might for convenience be classified in four divisions—the sterilization of liquids, purification of air, industrial applications and therapeutic applications. The electrical fraternity is not interested in therapeutic applications, except in producing satisfactory devices for the purpose. Scientific bodies, however, such as the chemical and electrical organizations, are particularly interested in the industrial applications. This field has been scarcely explored, except by a few isolated experiments, made rather at random, which indicate wonderful possibilities, for example, the application of ozone in the manufacture of linoleums and oilcloths, in the varnishing processes, transportation of fruits, preservation of meats, the aging of liquors and wines, the bleaching of fabrics, etc. All of the above applications are so rich in possibilities that it is difficult to cover them in a paper, such as that just presented, or a discussion of the paper, but I do wish to appeal to the Institute and other scientific bodies to encourage investigation of the subject, and the development of devices for producing ozone and their application, so that America may take rank with European and other foreign countries.

I hope at no distant time to be able to look to the literature of our own country, and the discussions and activities of our own scientific bodies, for information which now has to be sought and procured abroad. I am, therefore, glad to have had Dr. Franklin's paper presented to this body on this occasion, which is, I believe, the first time the subject has been discussed before an electrical engineering organization, and I trust we will have more of similar papers in the future.

J. Lester Woodbridge: Some years ago I had an opportunity to inspect an ozonizing plant for the purification of water, which was established in Philadelphia. It consisted of a series of tubes

each of which contained two strips of metal, provided with serrated edges, placed opposite to each other, edge to edge, across which a brush discharge was maintained by means of a combination of condensance and inductance arranged to transform from constant potential to constant current, no dielectric being interposed between the opposite points. A current of air was passed through the tubes, and ozonized by the brush discharge, and this was used for purifying the water.

I would ask Dr. Franklin whether that particular type of plant has made any further progress, or whether it has been entirely abandoned, and why?

I also learned, although I did not follow the matter up personally, that one of the difficulties in purifying water with ozone in certain cases was the fact that a large amount of vegetable matter in the water would seize the ozone first and use it up, before the ozone had an opportunity to destroy the bacteria, and I would ask Dr. Franklin if that is not one of the difficulties of purifying water in this way, where there is a large amount of vegetable organic matter in the water?

W. L. R. Emmet: I would like to ask Dr. Franklin whether there is any good means of knowing how much ozone we are getting, and what its quality is, whether it is free from nitrous oxide, and whether the ozonation of the air is completed, and also that of the water.

Many people are interested in knowing how water is sterilized by ozone. I do not know myself just how it is applied, but I should think it might be hard to get at every particle of water with certainty. I tried holding in the draft from the ozonator a glass with a little water on the surface of it which contained many microscopic organisms, to see whether there was any effect on these organisms. I could not see that there was any. They all seemed to relish it. I judge from this, that in sterilizing water, unless you go at it right, you might miss a few.

Milton W. Franklin: Referring to Mr. Emmet's experiment: Bacteria are minute unicellular structures, incapable of independent locomotion, and the slightest injury to the single cell which constitutes them results in death. The organisms which he observed were organized animalculæ of a relatively high order and therefore it would require large amounts of concentrated ozone in contact with them for a considerable period to cause their destruction. In the commercial purification of water by means of ozone the ozonized air and the water are brought into intimate contact by any of numerous processes whose aim is to finely divide the water as well as the air and to bring together, and to maintain in contact for a predetermined period, the particles of air and of water.

Referring to Mr. Skinner's question: Broadly speaking, anything which may be called a medicinal substance is a poison. It is something which, when introduced into the living organism, produces a physiological effect. If given in moderation, the

effect is only beneficial, but if the amounts administered are excessive, the effects are those of a poison, in the accepted meaning of that term. Ozone may be classed with these substances; in moderation its use is to be commended, but in excess it would undoubtedly produce untoward symptoms. However, it is extremely improbable that ozone is liable to be given in overdose as the warnings are so pronounced and so remote from the beginning of actual danger that nobody could persist in exposing himself in air that possessed even a small fraction of the amount capable of doing harm. In the sterilization of rooms the advantages of ozone are that it is nonpoisonous and that it is a gas. In the first place the elaborate precautions for sealing the room and for guarding against the harm which might be done by escaping cyanogen may be ignored, and in the second place the gaseous nature of the ozone insures that every crevice and corner in the room will be treated.

With respect to the presence of vegetable matter in water, if the amount is excessive, the removal of the vegetable matter by filtering before sterilizing with ozone will be found cheaper than removing it by ozone, though the latter may always be accomplished. The object of all filtering and purification processes is to produce the result sought cheaply and at the same time surely. There certainly can be no objection to the ozone process, if it accomplishes these ends, simply because it operates in conjunction with another process which alone does not suffice, but which, when combined with ozone, cheapens the application of the latter.

THE ECONOMICAL SPEED CONTROL OF ALTERNATING-CURRENT MOTORS DRIVING ROLLING MILLS

BY

F. W. MEYER and WILFRED SYKES

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THE ECONOMICAL SPEED CONTROL OF ALTERNATING-CURRENT MOTORS DRIVING ROLLING MILLS

BY F. W. MEYER AND WILFRED SYKES

For reasons which need not be discussed in this paper the induction motor has been adopted almost exclusively for driving rolling mills where electrical equipments have been installed. One of the most difficult problems to be solved with this type of motor when electrifying rolling mills is the speed regulation required for the merchant and hand mills, owing to the fact that this type of motor is normally a constant speed machine. It is also one of the requirements on which it is almost impossible to obtain reliable information and one which invariably leads to a great deal of discussion, not only between the electrical engineers and the mill operator, but also amongst the operators themselves. Although the principal types of mills requiring adjustable speed are the merchant and hand mills, it is occasionally necessary to run the mills rolling heavy sections at various speeds. In the latter case, however, the problem is usually fairly simple because as a rule only two speeds are asked for.

The smaller mills generally call for a great number of speeds and it is in connection with motors of about 300 to 1000 h.p. that the principal difficulty occurs.

In referring to adjustable speed drives it is understood that this means mills that have to run at a number of definite speeds and that these speeds are maintained substantially constant independent of the load variation.

To any one investigating the requirements of rolling mills, one of the most striking features is the diversity of opinion among mill operators, as to what speed regulation is necessary when

rolling various sizes of material and different classes of work. To explain clearly the problem, it is necessary to divide the mills into three classes as follows:

1. Speed adjustment is required on account of the large range of material required.

2. The speed regulation is required to enable a mill to run in tandem with another mill which has a fixed speed and which rolls a variety of product.

3. Speed regulation is required to make it possible to obtain certain qualities, finish, and accuracy of section for different products.

As a rule it is not clearly understood, but it is a fact nevertheless, that in the first case, the speed regulation required depends greatly upon the class of labor operating the mill, and to the degree to which it has been organized for working this particular plant. A gang of men that has been working together for a considerable period at a particular mill can naturally handle the metal quicker than one that is not so well organized and familiar with its characteristics, and it is also possible when the men are thoroughly familiar with the work to handle a large variety of sections at high speeds, than can be done by less skillful workmen. Where the range of material rolled is very great it is, of course, not possible to handle heavy sections properly at the same speed as the lighter sections, no matter how well the workmen may be trained. The rate at which it is possible for the workman to catch the metal with his tongs as it leaves the mill and return it to the roll, depends, within limits, entirely upon the skill he may have acquired through practise, and when rolling the smaller sections, it is the workman's capacity to handle the metal that limits the speed of the rolls. The more skill he has, the greater will be the range of material that he will be able to handle at the maximum speed of the mill, providing, of course, that the weight is not excessive, and this accounts to a very great extent for the difference in the practise of different mills when rolling the same material. It may be stated, therefore, that if the range of material rolled is not very great, the speed regulation required depends principally upon the skill of the workman. It is not unusual to find that after a mill has been installed with arrangements for speed regulation, and has been operating for a few months, that speeds lower than the maximum are not used at all.

As the greatest speed regulation is generally required by the smaller mills due to the larger range of material that must be

rolled with a given equipment it is in such plants that the best results can usually be obtained by studying the operating conditions and the organization of the workmen.

In changing an existing installation from steam to electric drive, it is very often possible to materially increase the output, due to the fact that the speed limitations of the induction motor necessarily introduces changes in the method of operation. If, for instance, a mill is installed with say only two speeds where previously a greater number were possible, it is commonly found that after a short time, a much greater variety of sections is rolled at the higher speed than was formerly the case. As the operators have only one alternative, it is, therefore, necessary to study very closely the working conditions, and by comparing them with those of other plants, to arrive at conclusions independently of the statements of the operators. Such methods must

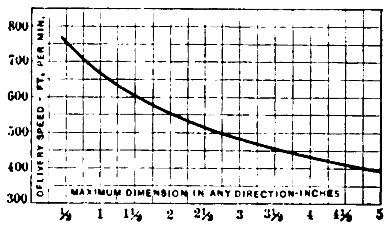


FIG. 1

not be pushed too far, of course, as the quality of the organization must also be taken into consideration. From investigations made as to the operating conditions in a great many mills driven by steam engines, it has been found that the operators usually have only a very vague notion of the speeds at which different materials are rolled. In Fig. 1 is shown some average figures for the delivery speed of hand operated mills and it will be noted that the speed depends upon the maximum dimensions of the material rather than upon the area of the section.

It is occasionally necessary to roll certain kinds of steel at lower speeds than the maximum on account of the quality of the material or the temperature at which it is worked, and this must, of course, be taken into consideration.

It is obvious that if a mill is to roll a great variety of sections some speed regulation may be necessary, but as it is not uncommon to find material rolled at speeds varying as much as 100 ft.

(30.4 m.) per minute from the average figures given, so it is obvious that a greater number of speeds is not absolutely necessary although very often asked for. The greatest speed adjustment is required in the case of jobbing mills where it is not unusual to find material varying from ¼ in. to 3 or 4 in. (0.63-cm. to 7.6 or 10.1-cm.) rounds rolled in the same mill, and a speed range of 2 to 1 may be required. With such a range of work it is necessary to finish the smaller sections at a higher speed than the larger ones, as otherwise, the metal would cool too rapidly and could only be formed by the expenditure of a great deal of power thereby, increasing the liability of breakage of the mill, and the accuracy of sections and quality of product may also be affected. To obtain a reasonable production from the mill, the smaller sections must be naturally rolled at as high a speed as possible.

The second conditon to be met is where the finishing stands of

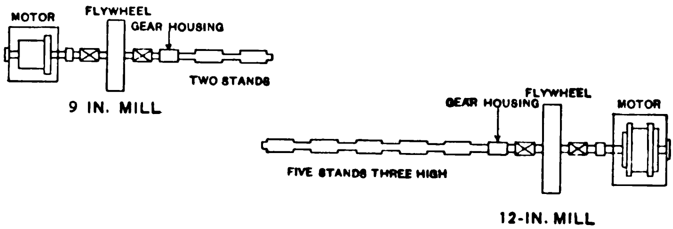


FIG. 2

a mill are driven by a separate motor, and the metal is in the two mills simultaneously. In this case the metal is usually delivered from the first mill at approximately constant speed and the speed of the finishing stands is dependent upon the reduction in area in the last passes. There is usually a loop between the two mills, but if the relative speeds are not approximately correct, the length of the loop may become excessive or the metal may be torn apart. In Fig. 2 is shown the layout of a mill of this type in which the smaller sections are finished in the separately driven rolls while the larger sizes of material are finished by the first mill. The delivery speed of the mill is approximately the same as the peripheral speed of the rolls, and consequently the intake speed will vary in proportion to the reduction in area in the pass. For instance, if there is a 30 per cent reduction in area, the ratio between the intake and delivery speeds will be the same as 70 to 100, or in other words the delivery speed will be 43 per cent

faster than the intake. This relative speed, of course, varies with each section rolled. Another feature controlling the delivery and intake speeds is the size of the rolls. In practise, rolls will vary in size 10 per cent; they are usually about 10 per cent over size when new, and they will be turned until they are about this amount under size, before they are discarded. If it should happen that the first mill has new rolls, and the finishing mill old rolls, there may be a difference between the delivery and intake speeds of 20 per cent independent of any other conditions that may exist.

The amount of variation from the correct speed of the finishing rolls depends upon the normal length of the loop, which should be as short as possible, the floor space available and the length of the material. It is, therefore, usually necessary with this arrangement to arrange for a fairly large speed regulation with a considerable number of steps.

The third condition is usually met with in mills rolling heavy and complicated sections. In such cases in order to roll some particular section accurately to size, a lower speed may be necessary than is required for normal operation, but in such cases only two speeds are usually wanted to meet operating conditions.

To meet these three conditions a number of arrangements have been used and suggested, and it is proposed to review some of these different schemes from a practical operating and commercial standpoint.

Rheostatic Control

The simplest method of reducing the speed of an induction motor is, of course, to insert resistance in the rotor circuit, by which means any speed required may be obtained for a certain definite load and with a corresponding loss of efficiency depending on the load and reduction in speed. With simple rheostatic control, we are limited by the speed variation which occurs with varying loads, as at light loads the motor speed will rise to approximately the maximum value no matter what the full load speed may be. Within certain limits, where the regulation required does not exceed about 10 to 15 per cent from the synchronous speed, the rheostatic method of control is not only the simplest and most satisfactory, but under mill operating conditions probably the most economical. In the class of mill requiring speed regulation, the load is usually comparatively constant, due to the fact that there is often more than one piece going hroug the mill at a time, and the interval between passes is

generally very short, so that the actual speed variations are not so great as it may be thought would be the case from the motor characteristics, especially if the flywheel effect of the rotating parts is at all appreciable. The effect of a flywheel is not only to lower the peak loads that come on the motor, but also to lengthen the time required for the motor to increase in speed after the load is reduced.

Without automatic regulation of the resistance, about 15 per cent regulation is about all that can be obtained under usual operating conditions, but sometimes a still greater range is practicable. With automatic resistance adjustment so as to vary it inversely with the load, it is usually possible to obtain a speed regulation up to about 30 per cent providing the friction load of the mill is not less than about 20 per cent of full load capacity of the motor, and there is sufficient flywheel effect in the mill to compensate for the time element of the regulator. Beyond these limits it is hardly practical to use rheostatic speed regulation, but up to about 30 per cent it is possible to obtain fairly satisfactory operation by rheostatic control under the above conditions. The accuracy of the regulation will depend somewhat upon the flywheel effect of the system and if it is very great even a greater range than given above may be obtained satisfactorily. Although at first sight, rheostatic control may not appear to be economical, where the speed range is as large as mentioned above, there are many cases where it is more economical than some auxiliary arrangement for obtaining speed regulation, due to the fact that at light load the rheostatic losses are not great and that the proportion of the time that the motor is operating at full load may be comparatively small.

If we consider for instance a jobbing mill which runs continuously, but which has a very small production, the no-load losses of any auxiliary arrangement may mean an appreciable reduction of the all day efficiency. Take for example a mill requiring 500 h.p. average when rolling and 100 h.p. running light, the motor losses being 10 per cent of the average output at full load, and 5 per cent at the friction load. If the mill carries full load, 20 per cent of the running time, and the regulation from synchronous speed required is 25 per cent, the additional loss due to the resistance will be about 22 per cent at full load, and at light load the rheostatic loss will be about 24.4 per cent. The total input to the motor under these conditions will be for one hour.

Useful output 500 h.p., 12 minutes	100 h.p-hr.
Motor loss, 50 h.p., 12 minutes	10 " "
Rheostatic loss, 140 h.p., 12 minutes	28 " "
Friction output, 100 h.p., 48 minutes	80 " "
Motor loss, 25 h.p., 48 minutes	20 " "
Rheostatic loss	32 " "
	270 h.p-hr.

The 25 per cent speed regulation has been obtained at the expense of an additional input of 60 h.p-hours. If instead of rheostatic control, the alternating current was converted to direct current by means of a synchronous converter the efficiency of the converting equipment including transformers would be about 90 per cent at full load and about 83 per cent at light load. In this case an adjustable speed motor would be used for the mill so the efficiency would be about the same as the induction motor. With this arrangement the input would be as follows:

Useful output, 500 h.p., 12 minutes	100 h.p-hr.
Motor loss, 50 h.p., 12 minutes	10 " "
Conversion loss 60 h.p., 12 minutes	12 " "
Friction output, 400 h.p., 48 minutes	80 " "
Motor loss, 25 h.p., 48 minutes	20 " "
Conversion loss, 25 h.p., 48 minutes	20 " "
	242 h.p-hr.

The overall efficiency with the rheostatic control would be

$$\frac{(100 + 80) \times 100}{270} = 66.6 \text{ per cent.}$$

and with the direct current system,

$$\frac{(100 + 80) \times 100}{242} = 74.3 \text{ per cent.}$$

An improvement of 7.7 per cent in the overall efficiency has been gained with a capital expenditure about 100 per cent greater than that of the simple induction motor. The fixed charges will be appreciably increased due to the greater outlay and the greater maintenance of the additional apparatus. Actually, the gain will be considerably less, as the mill will operate only a part of the time at the reduced speed. If, for instance, it runs half the time at the reduced speed, the overall

efficiency of the induction motor drive would be 75 per cent, and the direct-current drive 74.3 per cent, so there would be no saving in a year's operation.

This is not representative of the class of work usually met with, but such cases are not uncommon and it will be seen that although rheostatic control is inherently inefficient, yet in certain instances it might be better than some of the arrangements that are at present operating. In the example taken, the obvious solution of the problem would be to use a two-speed motor and to obtain intermediate speeds by rheostatic control, in which case the economy would be very much better than shown, and superior to the direct current arrangement. With some of the newer methods of speed regulation which will be referred to later, much more economical regulation can be obtained than with any arrangement requiring the conversion of the energy to direct current, so that the field for rheostatic control will be reduced in the future, but the difference between full-load and the yearly efficiency with rheostatic control, should be clearly understood.

Multi-Speed Motors

Theoretically it is possible to obtain practically any number of speeds required from a single motor by using one or more windings and suitably grouping the coils. In practise, however, we are limited to one or two combinations on account, not only of the complexity of the motor design and the uneconomical use of the material, but also because of the complication of the control equipment. Four speeds is about the maximum that can be obtained with multi-speed motors in practise and even this range requires an extremely complicated control, especially if the motor has a wound rotor. Two of the speeds need not have any definite relation to each other, but the other speeds in each case must be half of the corresponding higher speeds. This arrangement requires two windings on the stator and in the case of a wound-rotor motor, two windings on the rotor, each winding being grouped to give double the number of poles for the lower speed. To obtain the various combinations, such a motor must have at least nine slip rings, and 12 leads must be brought out from the stator.

The usual type of motor used in steel mills has not more than three speeds, one speed being half of the maximum and the third speed is intermediate between these two. This motor also

has two windings one of which must be re-connected to give a 2 to 1 ratio. Such arrangements are seldom met with and a great majority of cases, up to the present, have been taken care of by two-speed motors, intermediate regulation being obtained by rheostatic control. The simplest type has a speed ratio of 2 to 1 and has only one winding which is re-connected, requiring six stator and six rotor leads. The, second type has two windings that are absolutely independent of each other, but has the same number of leads as the motor with the 2 to 1 ratio. The complication of the control is one of the disadvantages of the multi-speed motor and it is one of the limiting features of the number of speeds that it is feasible to obtain. In the motor with two separate windings the control is very simple, as it is only necessary to change from one winding to the other by means of double throw switches.

With an arrangement giving two synchronous speeds, one approximately 70 per cent of the other, it is possible to obtain a speed regulation by rheostatic control of about 2 to 1, giving any number of intermediate steps that may be required. This arrangement in a great many cases where comparatively close regulation may be necessary, such as when mills are worked in tandem, may work out to be the best and cheapest installation.

A number of papers have been read before this Institute on the possible combinations for obtaining a number of synchronous speeds but in all the discussion little attention has been given to the switching arrangements required to make up such combinations. From the standpoint of the operator, the control equipment is usually a greater worry than the motor and an arrangement that may be technically very interesting and ingenious will be probably so complicated from a control standpoint that satisfactory operation is impossible. The motor is usually the simplest and most reliable part of the equipment and, therefore, it must not be considered alone. The order in which the switching must be done when changing from one speed to another to prevent short circuits is such that it is almost imperative to use automatic control with the class of labor usually operating such machines, and to obtain the proper combinations, the wiring becomes extremely complicated if more than two speeds are required.

The efficiency and power factor of the multi-speed motor is not very much lower than a single-speed machine of the same characteristics and from a practical operating standpoint, the difference is not appreciable.

Motors in Cascade

With motors in cascade it is possible to obtain practically any number of speeds that may be required. Actually the number of speeds that it is possible to obtain is limited by the cost of the equipment and the complication of control apparatus more than by any limitations of the system. This arrangement has been used to a slight extent here and to a greater extent abroad for rolling mill work, but on account of its high cost and rather unsatisfactory operating conditions it has not found many advocates.

The possible combinations have been brought out to some extent in the discussion of Reist and Maxwell's paper before this Institute,* and practically the only limitation is the number of steps that can be obtained with an even number of poles. Such combinations, however, could not be used in practise on account of the complexity of the switching devices which would be such that they would be necessarily very unreliable. The combinations that are really practicable do not give any greater range, than can be obtained by multi-speed motors and the efficiency and power factor is not as good. The low power factor of the cascade arrangement is one of the most undesirable features of this arrangement, and in steel mills where induction motors are so largely used the addition of such apparatus is very undesirable. The work that has been done in the study of the speed requirements of the mills by electrical engineers has shown that it is not necessary to have such a wide range of speeds as can be obtained with the cascade arrangement even leaving the practical side of the question out altogether, and, therefore, the multi-speed motor has been used almost exclusively in this country, where different speeds have been necessary.

Induction Motors in Conjunction with Three-Phase Commutator Regulating Machines

In the types of machines that have been referred to, the characteristics are generally well known. In the case of rheostatic control, the resistance losses are such that this system is not efficient if the amount of regulation required is large, as the energy from the rotor circuit is dissipated in the resistance. If instead, the energy from the rotor circuit is absorbed by an auxiliary machine or machines, which in turn delivers power to the system, it will be possible to obtain speed regulation below

*Transactions A.I.E.E., 1909, page 601.

synchronism economically. If energy is delivered to the rotor circuit by an auxiliary machine or machines, regulation above synchronism can be obtained. With such arrangements it is possible to combine many of the advantages of the induction motors with those of the adjustable speed direct-current motors. The desirability of such regulating systems cannot be questioned, but under the conditions existing in this country, there are at present certain difficulties standing in the way of the general adoption of the various methods which will be described. The problem of adapting these various systems to American conditions presents considerable difficulty and consequently they cannot be generally used at the present time.

The various systems that have been developed enable speed regulation over a considerable range to be obtained, and in addition to their use in connection with rolling mill motors they have been largely adopted in Europe for the speed control of compressors, blowers, etc., as well as for the driving of machine tools requiring adjustable speed, thereby supplanting the adjustable speed direct-current motor, and making possible the use of alternating current for all purposes.

The desirability of obtaining a greater speed range economically than is possible with the multi-speed motor and cascade systems that have been previously described, caused some of the European manufacturers to experiment at an early date with the various arrangements involving three-phase commutator motors. In spite of the favorable results obtained under test conditions the development of these arrangements progressed rather slowly, due to the fact that this type of machine introduced new problems from an operating standpoint, and consequently, practical experience had to be first obtained before confidence was established. Originally, there was considerable doubt as to the possibility of obtaining satisfactory commutation, but the development of the single-phase commutator motor for railway work, operating under most severe conditions, paved the way for the introduction of a three-phase commutator motor. One of the difficulties that had to be overcome in the introduction of this type of motor was the education of the operators. In Europe, the experience that had been gained with the single-phase motor showed that the three-phase machine did not present any greater difficulties, as far as commutation is concerned and in certain features had advantages over the single-phase, and in some respects even over direct-current machines, in spite of other drawbacks.

How far it is possible to use the systems that have been developed in Europe, in this country, is a question that can only be demonstrated by experience, but in view of the inferior class of labor that we have in a great many of our plants for attending to the machines, it will be necessary to exercise considerable care in the early installations. As it will be seen from the following descriptions of the various systems some of them are quite simple, and when the preliminary difficulties have been overcome, we may expect that such arrangements will find considerable application. In a paper before this Institute, Mr. G. A. Maier* described some of the systems that have been developed in Europe, and in the discussion another system was mentioned. It is proposed in this paper to describe some of the newer developments with this type of machine and for the sake of comparison, the principal features of the systems already described will be mentioned. Most of the main characteristics of the new systems that will be described have been already tested, but at the present time it is not possible to discuss operating experience.

One characteristic of the three-phase commutator regulating machine is that it is possible with suitable arrangements to compensate for the power factor of the main motor and overcome the objections that are raised as to the use of induction motors, on account of their low average power factor. This characteristic has not been taken full advantage of in all systems that have been developed, but it is one of the important advantages of this method of regulation.

One of the first systems developed had the commutator machine direct connected to an induction motor shaft. This system has worked satisfactorily, but the question is sometimes asked why the three-phase motor is not used directly instead of in combination with the induction motor. The reason is that it is desired as much as possible to employ the simple induction motor for performing the work and that the commutator machine is only used as an auxiliary to obtain the speed regulation, and consequently it may be smaller in most cases than would be the case if it were used directly.

In Fig. 3, the system referred to above is shown diagrammatically. The induction motor A is designed for the full load to be carried. When the main is operating at its full speed the auxiliary motor B is not loaded and may be disconnected altogether. In order to obtain a reduction in speed, the exciting transformer

*Proceedings A.I.E.E., December, 1911.

C is so regulated that the auxiliary motor B develops a back e.m.f. which can be only overcome by an increase in the rotor voltage and a consequent drop in speed, and consequently, the energy from the rotor circuit, instead of being lost in resistance as with rheostatic control, is absorbed by the auxiliary motor which assists the main motor in carrying the load. So long as the speed range of the main motor is not large, the auxiliary motor is comparatively small, but its capacity is determined by the percentage of speed regulation required, or, for instance, if the speed must be reduced 30 per cent, it must have 30 per cent of the capacity of the induction motor. This is important, as previously it was not possible to build three-phase commutator motors for large capacities. The limit of size was fixed by the fact that satisfactory means were not available to obtain good

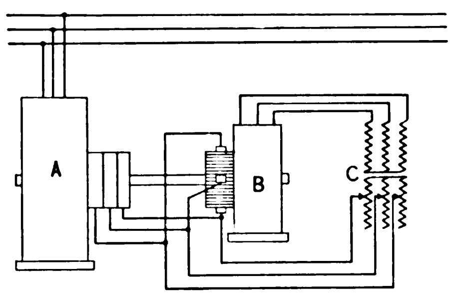


FIG. 3

commutation, and the arrangements for obtaining power factor regulation, by means of moving the brushes, made it extremely difficult to use auxiliary commutating fields in the motor. The movement of the brushes was necessary to avoid the use of an expensive combined phase and voltage regulator in place of the simple regulating transformer. Due to later developments, the limit placed upon the size of machine by the commutation has been removed by the use of commutating fields, which makes it necessary with the ordinary phase winding to use a constant brush lead to obtain good power factor compensation for the average operating conditions; or it is possible to obtain the same results by a special phase combination in the motor itself. The latter arrangement has certain advantages especially where the field form is not favorable to good commutation, which is not possessed by the system of varying the brush position,

This system of speed regulation has the advantage that as the speed of the set is reduced, the available torque for the same line current is increased as the work done by the commutator machine increases, directly in proportion with the decrease of speed. The disadvantage of this system is that the direct connection of the commutator motor necessitates it being designed for the same speed as the induction motor which as a rule, in the case of machines of large capacities in rolling mills is comparatively low, and this introduces difficulties in the construction. In the case of high-speed induction motors, driving turbo-compressors, blowers, etc., it is generally quite impossible to build the commutator motor for the same speed as the main motor. It is, of

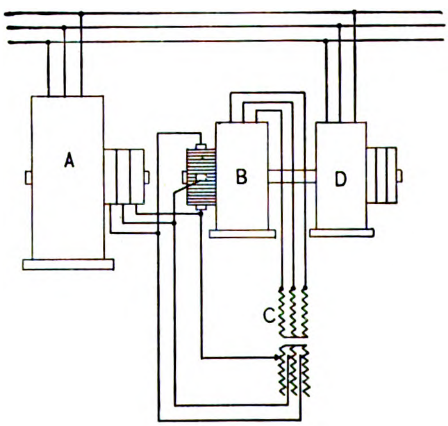


FIG. 4

course, possible to connect the commutator motor to the main motor through some form of gearing, but such arrangements should be avoided if possible.

The well known system shown in Fig. 4 presents advantages in this respect. In this figure the commutator motor *B* is not connected to the main motor *A* mechanically, but is coupled to an induction machine *D* which is connected to the line. This makes it possible to build the auxiliary machines for the most desirable speed, from a designing standpoint. The energy from the rotor circuit is not transmitted to the shaft of the main motor, but is transmitted through the auxiliary machines and is returned to the line in the form of electrical energy, and consequently this arrangement is better adapted for cases where

constant torque is required. The commutator motors of such regulating sets are nearly always provided with a compensating winding on the stator which counteracts the rotor field and makes it possible to regulate the speed by varying the magnetizing current. Consequently, the regulating transformer C and the necessary controller can be quite small. It would be possible to avoid the use of a regulating transformer altogether if the commutator machine is provided with an auto-transformer winding which has been done in a number of cases with the system first described.

The power factor compensation with this system is obtained by a special phase combination somewhat different to that used with the arrangement previously described, but such an arrangement provides only correct compensation for one definite speed

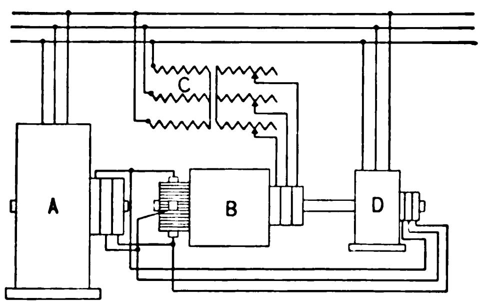


FIG. 5

and load, which are chosen so as to approximate as closely as possible, the average working conditions.

In the system just described the commutator machine has been in some cases furnished with a series pole for obtaining the characteristics of a compound motor, which is an advantage for instance if this arrangement is used in conjunction with the motor driving a rolling mill requiring a drooping speed characteristic. to enable the flywheel to take the proper proportion of the load.

The principal disadvantage of this system is that it requires two auxiliary machines to obtain regulation and it will be shown later that it is possible with suitable arrangements to avoid this feature.

In Fig. 5 is shown diagrammatically a system that has been used to some extent in Europe and which has been mentioned in the discussion of G. A. Maier's paper before this Institute. In this

arrangement the second auxiliary machine D is a small motor which drives the frequency changer B and only has to overcome the mechanical losses. The commutator machine B consists of a wound rotor which has on one side a commutator and on the other, slip rings. On the stator there is only an auxiliary winding for improving the commutation of the machine. This machine cannot develop any torque and it is, therefore, necessary to use the small driving machine D to rotate it relatively in synchronism with the main motor. The regulating transformer C must in this case be designed for the whole of the rotor energy, which flows through the frequency changer and the transformer to the line. In the frequency changer the copper losses are comparable with those of a synchronous converter and are consequently very small.

With this system as it has been pointed out, it is necessary for the frequency changer to run relatively in synchronism with the main motor, and consequently if the number of poles of the auxiliary machine D and the main motor were the same, which, however, is generally not the case, both would have to run at exactly the same speed. The rotor connections between the motor A and the auxiliary driving motor D insure that the machines remain relatively in synchronism and any slight difference will cause the exchange of synchronizing energy in the same way as with synchronous machines. The power factor of this system is fairly good on account of the favorable distribution of the magnetizing current, but it is not possible to obtain regulation. The advantage of this system over the arrangement previously described is that it is possible to supply energy to the rotor circuit so as to regulate above synchronous speed. With the previously described arrangements it is extremely difficult to cause the main motor to pass through synchronism. As it is possible to divide the regulating range above and below synchronous speeds of the main motor, the auxiliary machine need be only designed for half the capacity that would be necessary if the whole of the regulation was done below synchronism. This arrangement presents certain advantages when a higher speed than normal is occasionally required; for instance, in the case of blowers, where a higher pressure than normal may be required for a short period, the machine being run above synchronism when this necessary. To make it possible to obtain a definite speed variation between no-load and full load a compounding transformer has been used which gives such a characteristic.

Suggestions have been made for the simplification of this system by modifying the frequency changer, but they introduce undesirable characteristics such as poor power factor. The power factor might be sometimes improved by such arrangements as brush moving or phase combinations, but in such modified arrangements, the range of regulation required is greater than is necessary with the types of machines previously described, and consequently, it is more difficult to obtain a phase combination or to set the brushes in such a position as to obtain an average power factor that will be satisfactory under operating conditions. It is possible to simplify the arrangement somewhat by coupling the frequency changer to the main motor which obviates the use of the auxiliary driving machine, or the frequency changer may be geared to the main motor so as to obtain favorable construction speed, and as the power to be transmitted is trifling, the gearing can be of small dimensions. If the gearing is so arranged as to make it possible to change the relative rotor position of the motor and the frequency changer, power factor regulation can be obtained, and it is also possible to use a phase and voltage regulator for the same purpose. Such arrangements for connecting the two machines together are not very desirable and although possible, should be avoided.

From what has already been described it will be seen that there are many desirable features not covered by the systems hitherto in use, and it is, therefore, not astonishing that even recently arrangements have been used by which the rotor energy is converted into direct current and then to alternating current and returned to the line. For American conditions where 25 cycles is standard for heavy power work, such a system presents many disadvantages not only on account of constructive difficulties, but also on account of the high cost compared with other arrangements, although it has the advantage of using machines that are familiar to the attendants.

Although it is not possible in this paper to discuss all of the improvments that have been made, some of the latest developments may be described. It is not proposed to discuss the theoretical features of the various machines and systems as these will be given in another publication. The arrangement shown in Fig. 6 is one that is particularly suitable for rolling mill and mining applications and it will be seen that it is very simple. There is only a single auxiliary machine, the frequency changer *B*, which has a simple three-phase winding on the stator which need only

be designed for a comparatively small current and which is connected to a small regulating resistance. In addition, an auxiliary winding is provided to improve the commutation. As in addition to this regulating resistance there is also provided the regulating transformer *C*, it is possible to regulate the whole system in two ways, which are necessary to control independently the power factor and the speed. The operation of this system can be understood from the following: Let us suppose the motor *A* is brought to a certain motor starting as an ordinary induction motor, with rotor resistance and the connection to the frequency changer being open. The frequency changer may be also started as follows: Rotor *R* of the frequency changer *B*

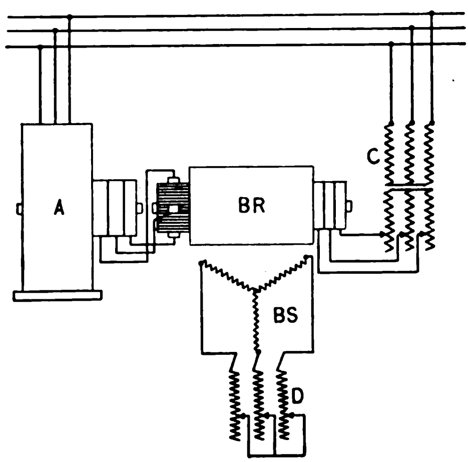


FIG. 6

is supplied through the regulating transformer *C* with voltage to correspond to the desired voltage on the rotor of the main motor, and the stator winding of the frequency changer *B S* which in this case is the secondary, is regulated by the resistance *D* until it runs relatively in synchronism with the main motor *A*. If, for instance, both the main motor and the auxiliary machine have the same number of poles, which, however, is generally not the case, then both machines must run at exactly the same speed. As for example, if the voltage of the rotor of the main motor at stand still is 200 volts, and the speed is to be regulated to half the normal, the rotor voltage will be 100 volts which must also be the case of the voltage on the commutator and

slip rings of the frequency changer. If the ratio of the secondary and primary windings of the frequency changer is 1 to 1 then the voltage across the stator winding of the frequency changer must be regulated for 50 volts. The frequency of the induction motor rotor circuit is the same as that on the commutator and the stator of the frequency changer. By means of synchronizing lamps between the commutator of the frequency changer and the slip rings of the main motor, the two machines can be synchronized. If the starting resistance of the main motor is disconnected, the rotor energy will flow through the frequency changer and the regulating transformer to the line. The current in the stator of the frequency changer can be comparatively small as the field generated by the current flowing through the commutator is counteracted by the current flowing to the transformer through the slip rings with the exception of that necessary for the magnetizing of the working field, which is only sufficient to give enough torque to enable the machine to run at the proper speed. The method mentioned for synchronizing the frequency changer and the main motor is in practice unnecessary and is only used to illustrate the process.

An interesting question is what happens when the stator winding only is regulated by means of the resistance *D*, or only the transformer is regulated. It has been held that under such conditions stability of operation is questionable. The whole question of relative synchronous operation in general is interesting and difficult to solve which occasionally has led to a misunderstanding of the whole problem, as for instance in the newly published book of Arnold* on single-phase and three-phase commutator motors. Practical results, however, have settled all doubts on this question and have confirmed the theoretical foundations for this system. The theory shows that by such regulation, power factor compensation of the whole power circuit is possible as far as may be desirable. If, for example, the resistance *D* is increased without changing the regulation of the transformer *C*, the frequency changer has a tendency to run faster, but this is impossible on account of its connection to the main motor, and the only result is that an equalizing current will flow between the two rotors, therefore, causing a synchronizing force. It is consequently the case that by suitable regulation of this current, the power factor to the whole system can be set at any desired value. This result can be somewhat explained by

*Volume 5-A, Wechelstromtechnik.

means of the vector diagram in Fig. 7. The uncompensated induction motor with resistance regulation will take the current I' which will be behind the voltage E. In operation with the auxiliary machine, there flows the current I_a in the stator of the motor which leads the voltage E and at the transformer we have the current I_b which lags very much behind the voltage component. The resultant of both these currents gives the current I which is more or less in the direction of the vector E and consequently the power factor can be brought to the desired value. As a diagram of the internal action of the commutator machine would show, the regulating transformer supplies a strong wattless component of the current I_b which produces the field of the auxiliary machine and also that of the induction motor. However, by the regulation of the stator winding of the frequency

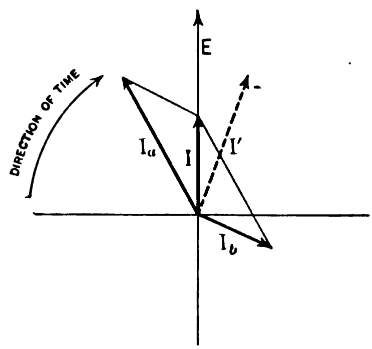


Fig. 7

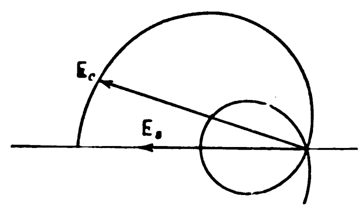


Fig. 8

changer a greater wattless component is produced than is necessary for the production of these fields and this has the effect that the main motor current can be made leading so that the resulting current comes into the right phase relation. It should be kept in mind that, although at the transformer there is an increase in the magnetizing current, there is not a corresponding decrease in the induction motor. If we assume a ratio of 1 to 1 between rotor and stator in the induction motor, there will be the same leading component in the primary as there is a surplus lagging component in the secondary, which is independent of the voltages of the rotor and stator, and also of the speed. It is questionable whether it is advisable to compensate for the power factor of other machines on the line by such methods, but if this is done, it will have practically no effect on

the stability of the machines, as good machines are capable of standing two or three times the normal torque, and oscillation between the machines seldom occurs even if no particular effort are made to avoid it. The main motor and the regulating machine operate only relatively in synchronism and not in synchronism with the line.

The speed of the sets varies somewhat when the power factor is regulated, being caused by the fact that the voltage drop in the machines varies somewhat when the wattless current is changed. In a simple case, with constant torque on the motor and other conditions remaining unchanged, we obtain from a detailed investigation of the characteristics, the curve shown in Fig. 8, which shows the variation of the commutator voltage E_c in comparison with the assumed constant slip ring voltage E_s. This variation is the reason why the speed changes somewhat when the power factor is regulated. When there is an improvement in the power factor, the speed increases. If the load is varied, we also have variation in the speed of the set which decreases as the load increases, and this characteristic can be taken advantage of in case of motors driving rolling mills to enable the flywheel to take its proper proportion of the load. The drop in speed is naturally dependent upon the resistance and self-induction of the frequency changer, leaving out the question the characteristics of the main motor, and if the set is regulated for a certain speed, the speed characteristic is similar to that of a shunt motor. It should be noted that on account of the interaction of the machines, even if the frequency changer were non-inductive, it would be possible to obtain satisfactory operation which is an important difference from the characteristics of synchronous machines. Even with such a condition, it would still be possible to compensate for power factor, but in view of the fact that it is desired to obtain a good power factor, as constant as possible without regulation over a wide range of load, it is desirable to have some induction in the rotor circuit. By varying the self-induction in the rotor circuit, it is possible to change the speed characteristics from no-load to full load and this may be done without interfering with the capacity of the machine to regulate the power factor. If variations in the power factor are permissible, it is possible to obtain a very fine speed regulation by regulating it, and consequently the regulating transformer need not have so many steps. The inner part of the voltage curve, Fig. 8, corresponds to the operation of the set

above synchronism, and it is clear from theoretical consideration of the effect of regulating the machine, the speed must eventually rise above synchronism, although with the constant voltage E_s there would be heavy current flowing at the synchronous speed. It is a very interesting question as to how it is possible to obtain such a curve practically; as also is the whole subject of operation above synchronous speed. It might be mentioned, in this connection that by means of phase transposition, the frequency changer can run as much below synchronism as the main rotor is to run above synchronism. The necessity for the transposition of the phases can be avoided by modifying the system somewhat, and whole operation of the set at and above synchronous speed can be improved by such modification, but this point can-

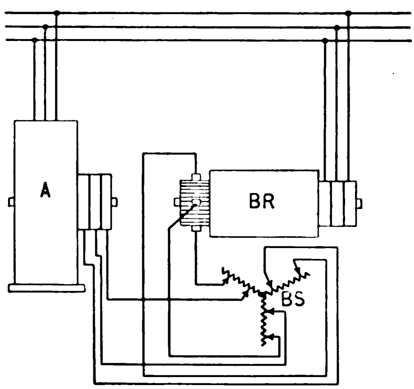


FIG. 9

not be discussed at the present time. The system that has just been described is very simple on account of the fact that we have only a single regulating machine instead of a number of machines, and it is easily regulated as it is only necessary to regulate the transformer in any way that may be convenient, or an induction regulator might be used which would avoid handling the regulating current altogether. On account of the fact that the current in the stator is very small and need not be regulated in fine steps there is no difficulty whatever in controlling this circuit.

It is possible to avoid the use of the regulating transformer in the case of low-voltage circuits as shown in Fig. 9. In this case, we have also the main motor *A* and the frequency changer *B* with the rotor *R* and the stator *S*. The stator is provided with

an auto-transformer winding and the function of the regulating transformer is combined in the machine. It will be seen, however, that the stator winding can be regulated in two ways, and this makes it possible to regulate both speed and power factor as in the system previously described. If we suppose the frequency changer is running relatively in synchronism with the main motor and also has the right voltage, the two machines can be connected together. If the stator is now regulated in such a way that the transformer ratio remains the same, but at the same time, the absolute number of active turns is varied and consequently the field, the wattless current will change and the power factor can be regulated. The whole of the regulation can be taken care of by a single controller which can be very simple, as it is unnecessary to regulate the power factor in fine steps. All of the characteristics required of the motors driving the mills or machines can be readily met by interlocking the various elements of the controller. This arrangement does not require any changes in the windings of the machines, nor is it necessary to move the brushes, or to have any variable gearing between the main motor and the auxiliary machine to obtain power factor regulation. The auxiliary machine combines in itself all of the regulating requirements and is, therefore,

Voltage regulator,
Frequency changer,
Power factor regulator,
Motor for driving itself.

By various arrangements it is possible to obtain entirely satisfactory operation above synchronism and in fact, it is just as easy to operate above synchronism as below and the passing through synchronous speed of the main motor does not present any particular difficulties.

When it is necessary to work near or at synchronism it is far better, however, to use such an arrangement as is shown in Fig. 10, although it is possible in the system just described to obtain a working field at the synchronous speed. The system shown by Fig. 10 provides for an almost constant working field under all conditions. The system shown in Fig. 9 is more suitable for regulating the speed in fairly large steps, and when the motor is running at such a speed as not to require the use of the auxiliary machine it can be disconnected and used for regulating the power factor of the line. The arrangement shown in Fig. 10, on the other hand, is more suitable for regulation in fine steps near the

synchronous speed, but the auxiliary machine is somewhat more expensive. This system is desirable where speed regulation is required, where the size of machine does not determine the type, but other technical reasons make it desirable to use such a regulating system. This is for instance, the case with turbo-compressors or blowers, which generally run at very high speeds, and even with comparatively small equipments it would be impossible to use any type of commutator machine directly. Consequently it is necessary to use an induction motor, and to obtain necessary speed regulation by some such system as has been described. The characteristics of blowers and compressors are such that only comparatively small speed changes are required to cause a considerable difference in the output, as the power varies

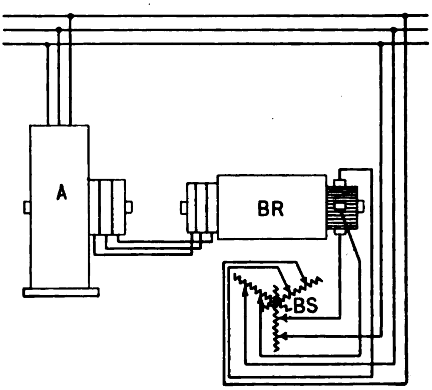


Fig. 10

practically as the cube of the speed. The regulation is obtained in a similar way to that described in the previous system and to obtain operation above synchronous speed it is possible to use a continuation of the phase winding through the star of the stator. A further development of the three-phase commutator machine for the purpose of obtaining motors for main drives as well as for regulating induction motors, however, makes it possible to avoid the use of such an unsymmetrical phase arrangement.

It is sometimes the case that the requirements of such systems are severe and that high momentary overloads or severe overloads for a comparatively short time must be carried, such as, for instance, in the case of rolling mills, blowers, compressors,

etc. These characteristics can be obtained with such a combination either at starting or at high speeds, under or above synchronism. In some cases it would be advantageous if the frequency changer could also be used as a motor at the same time retaining the function of the frequency changer which would give a good combination for running above or below synchronism. Such an arrangement would present a number of advantages in some cases, but is only possible if the auxiliary machine is mechanically connected in some way with the main motor. It may be also desirable to use a mechanical connection on account of the quickness of the speed variation required. To obtain such characteristics and to keep the advantages already mentioned, new arrangements are necessary, and it might be mentioned that such a system has been already worked out, but it cannot be described at present.

Three-Phase Commutator Motors

Operating difficulties exist when a very large speed range is required when the speed is reduced practically to zero, and in such a case a regulating auxiliary machine presents no advantages as it would have to be designed for practically the same capacity as the main motor. In such a case the commutator motor can be used for direct drive except when it is necessary to regulate the speed very much above synchronism, when it may be desirable on account of the commutator speed to use an induction motor and to operate the regulating commutator machine correspondingly below synchronism. In the case of drives of small power, the commutator motor used directly is quite satisfactory, but even in the case of motors of large capacity, there is no particular constructive difficulty in the way so long as care is taken to provide good commutating fields and such devices as brush moving are avoided. Some method of providing a good commutating field is, however, necessary, as for instance, with an eight-pole motor designed without commutating poles or other means of helping commutation, for 50 cycles, the limit of construction is about 150 to 200 h.p. In the United States the conditions in the steel plants are favorable for such machines on account of the almost universal adaptation of 25 cycles. Until recently only one type of such machine with shunt characteristics was in use in Europe. This type has at present such characteristics that the voltage for the rotor is supplied by an auto-transformer winding from the stator with a special phase combination or an arrangement

with auxiliary phases. This design makes it possible to obtain power factor compensation for one particular load and speed which is chosen so as to approximate the average operating conditions. To give power factor correction over a wide range of load and speed when this is desirable, such a system becomes so complicated as to be impracticable. In the following there is described a system which avoids all of these phase combinations and auxiliary phases as well as fixed phase relations at all, and also the necessity of brush moving. This machine is constructed not only with a rotor similar to a direct current machine, but

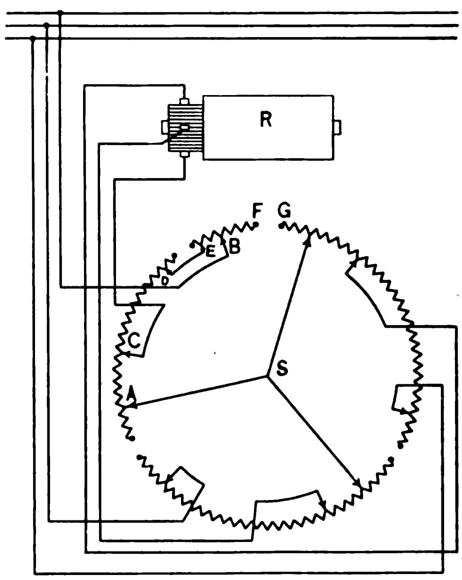


FIG. 11

also with a field of the same type which enables the speed, power factor and starting torque to be regulated. It should be noted that the machine with such a winding usually prevents the formation of excessive disturbing fields for the commutation. The newer developments of the winding have made it possible to regulate even over a very large range without introducing disturbing fields. Such machines have, however, in every case a simple continuous winding without auxiliary phases. The diagram shown in Fig. 11 illustrates the principles involved for all cases as far as regulation is concerned. This diagram

shows most of the possible variations, but it is necessary when designing such machines to determine how far the different possibilities can be taken advantage of. The same results as shown in the vector diagram, Fig. 7 are here obtained by the use of a single machine giving the phase regulation. From Fig. 11 it will be seen that it is possible to obtain the phase regulation by shifting the connections, and at the same time to vary the field and the voltage, or in other words this arrangement allows of a direct regulation of the vectors. For this purpose the stator winding has a number of divisions as shown by the spaces *D E* and *F G*. How many divisions are necessary in the stator winding is a question which depends upon the amount of copper in the winding. In any case, however, there must be at least three in these phase segments, which it will be understood can be displaced if required. From this diagram it can be seen that it is possible to shift the field and at the same time to vary its strength. The line voltage is applied between *B* and *A*. On the segment *A B* the voltage vector for the rotor can be set between *A C*. It will be, of course, understood that the rotor circuit can also be supplied from a special winding which is independent of the main winding. This circuit need only be designed to carry the regulating power, which arrangement is particularly advantageous when machine is designed for higher voltages. In this way, we obtain another possibility of varying the vector displacements which can be partly substituted for the other vector regulation. The whole question of such winding combinations which is connected with the question of the maintenance of the field form, and the reduction of the current to be handled by the controlling devices as well as the type of winding is too complicated to be discussed in this paper. The speed of the motor can be varied for instance either by varying the position of the point *B*, thereby changing the field, or by varying the position of the point *C* which changes the rotor voltage, and in either case the phase connection *A* can be so regulated as to give good power factor. This system has the advantage that the necessary commutating field can be supplied directly in the correct phase relation on the stator winding by proper connections. Fig. 12, shows how this same arrangement can be used for a motor with series characteristics. This diagram shows the phase connections *A* and *B* and the division points *C D*, *E F*, etc., and it is believed that no further explanation is necessary. In this paper which describes some of the latest developments in

this class of work and only mentions the well-known other systems for the sake of comparison, we have avoided altogether, any reference to the names of the various arrangements and also to the historical development, but it is generally known, however, that the series three-phase motor is very old. As originally built it had the disadvantage that the speed could only be regulated by shifting the brushes which caused the machine to operate with very poor power factor. The newly developed machines with brush shifting arrangements also have the same disadvantage even when the operating characteristics are favorable. Such an arrangement also has the disadvantage of high cost on account

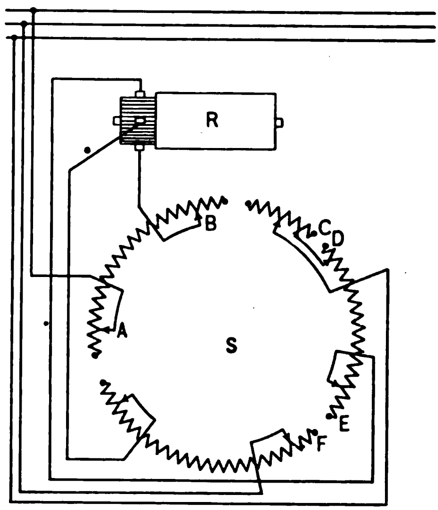


FIG. 12

of the lack of a good commutating field. If in addition to shifting the brushes the number of turns on the stator is also regulated, the whole machine becomes very complicated. The arrangement shown in Fig. 12 offers a better solution of the problem as it avoids these disadvantages and presents a number of very desirable features. The combination of the series and shunt systems gives the characteristics of a compound-wound motor which is of special importance where it is necessary to use a flywheel. The combination of such an arrangement with the regulating sets previously described gives a series of possibilities that can be obtained with standard construction of commutator

machine which may at times be useful. Further discussion of such special applications as for instance, arrangements to avoid the use of the expensive and rather inefficient flywheel motor-generator sets must be left for another occasion.

The various arrangements involving the use of three-phase commutator machines make possible the efficient regulation of induction motors, but they introduce a new problem in the use of the commutator machine itself. The results obtained in Europe, where the class of attendants is usually very much better than here, have been very favorable, but under American conditions any attempt to simply follow European practice would probably give disastrous results. As it has been pointed out, considerable care must be exercised in the first installations, and we may expect difficulties which can be only overcome by a sympathetic cooperation between the user and the manufacturer. The use of a regulating machine in conjunction with an induction motor offers many advantages over the direct use of the commutator motor when the speed range is not large, not the least being the comparatively low frequency of the rotor circuit. The extensive use of this type of machine may be looked for in the future, but in any case to insure success careful application is absolutely necessary.

COMPARATIVE TESTS

ON

HIGH-TENSION SUSPENSION INSULATORS

BY

P. W. SOTHMAN

Presented under the auspices of the

High-Tension Transmission Committee

A paper to be presented at the 278th Meeting of the American Institute of Electrical Engineers, New York, December 13, 1912

COMPARATIVE TESTS ON HIGH-TENSION SUSPENSION INSULATORS

BY P. W. SOTHMAN

This paper presents an account of work done in connection with the selection of a suitable high-tension insulator for a transmission line operated at 110,000 volts. It is a report of an investigation giving a faithful account of the motives calling for the same, the method adopted and used to carry out the work, and the line of reasoning followed in classifying the results obtained. It is not intended to be a criticism of any individual design or of the valuable work which has been done by others in the same direction. The problem which had to be solved was well defined, requiring no more difficult task than to select from a number of insulators the one best suited for certain predetermined conditions. From the first to the last, the question was one concerned with engineering only, in which biased opinion or partiality was to be absolutely absent. How well this problem has been solved may be judged from the following account and perhaps more so by the tangible results obtained in the years following, during actual operation.

When it was found that the line losses of the proposed power transmission could not be kept at a reasonably low figure unless the system was operated at 110,000 volts between conductors, the question of insulation became at once of greatest importance. Unfortunately, at that time, very little reliable data was available with regard to the operating experience with potentials above 60,000 or 80,000 volts. Notwithstanding the lack of such practical experience, every manufacturer was ready to offer and guarantee an insulator for a transmission line operating at 110,000 volts. Before an attempt was made to draw up specifications

for these insulators, a thorough canvass of the situation was made. The different insulator factories were visited to ascertain the manufacturing facilities of the firms and their ability to turn out a rather large order within a specified time. Tests on the proposed insulators were witnessed at the works of the manufacturers and all available information and data bearing on the subject was collected.

While visiting these factories, one could not help being most peculiarly impressed by the widely varying methods of testing employed by the manufacturers to demonstrate the merits of their insulators. This applies especially to the application of artificial rain and to the facilities afforded for observing the effect of the test. As a matter of fact, every manufacturer had his own way of applying rain, and of interpreting the effects observed. It can easily be understood why tests on one and the same type of insulator would show two entirely different results, depending upon where and by whom they were tested.

In view of the seemingly erratic behavior of the insulators during these manufacturers' tests, it was impossible to arrive at a definite conclusion. It became apparent that tests of this character should be performed under absolutely unvarying conditions in order to arrive at reliable figures, and arrangements were at once made to duplicate and elaborate these tests under conditions which could be controlled and changed at will to suit certain predetermined requirements.

The testing equipment of which use was made in the following tests, consisted of a large platform over which was placed a gas pipe, resting at each end upon 60,000-volt pin-type insulators. The insulators were tested one at a time, the small trolley from which they were suspended being moved opposite a mark made in the pipe midway between the supporting insulators, while all other insulators were crowded to one side and out of the way. The test on one insulator completed, it was moved to one side, and the next insulator placed in the proper position. This method proved to work out very well, especially in connection with the rain test described later.

The electrical apparatus consisted of two 50-kw. 2200/150,000-volt transformers in series, fed from a 25-kw. 220/2200-volt transformer.

The maximum voltage which could be safely obtained with this combination was slightly above 330,000 volts, with the two transformers in series, the neutral point being grounded, and 225,-

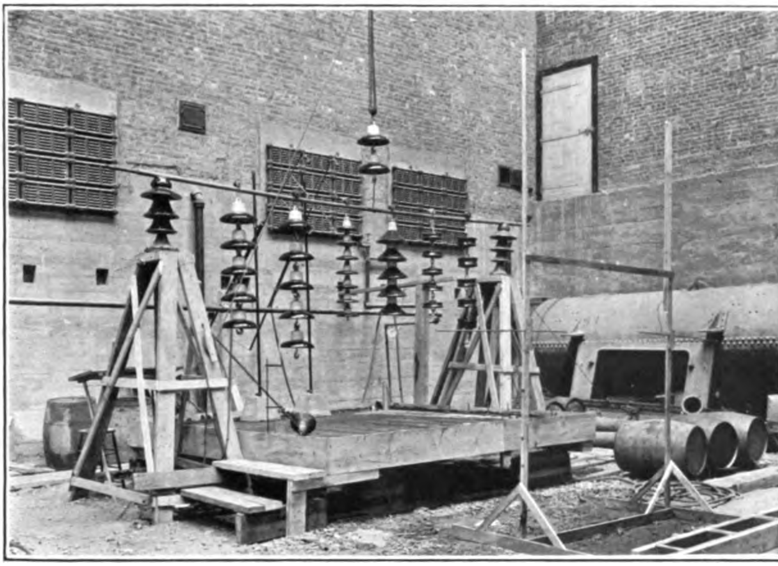


FIG. 1—TESTING PLATFORM FOR SUSPENSION INSULATORS [SOTHMAN]

Insulators supported fron Insulated Pipe on small trolleys—Note Groups of Nozzles in background for wet tests—Also spark gap in front—Rain gage is shown on left of platform.

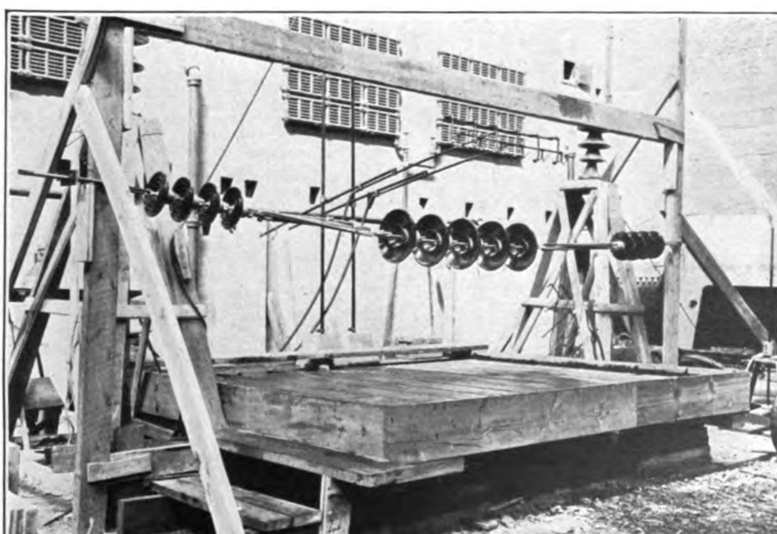
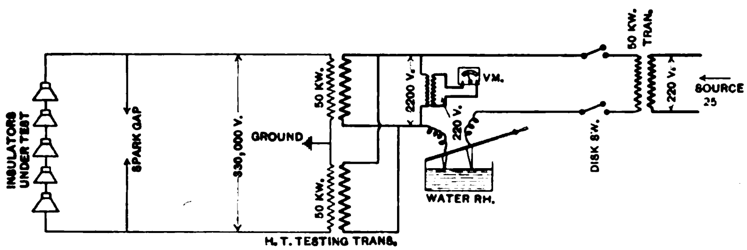


FIG. 5.—TESTING PLATFORM FOR STRAIN INSULATORS [SOTHMAN]

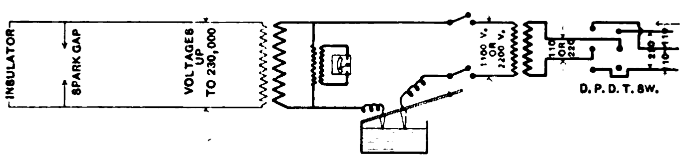
Insulator sections at either end of Insulator under tests are inserted to prevent leakage to ground. Nozzles are located directly above Insulator.

000 volts with one transformer alone and ungrounded. The voltage was controlled by means of a water rheostat in the low-tension circuit of the high-tension transformer. The readings were taken on an alternating-current voltmeter previously calibrated with spark gap in accordance with the Standardization Rules of the A. I. E. E. (1907). The voltmeter was connected across the low-tension side of a one-kw., 2200/110-volt transformer, the latter being connected across the low-tension side of the high-tension transformer.

All tests were performed at night in complete darkness. In order to have a permanent record for comparison, photographs were taken of each insulator during the several tests. The time



CONNECTIONS OF TWO TRANSFORMERS FOR 330,000 VOLTS



CONNECTIONS OF SINGLE TRANSFORMERS FOR 230,000 VOLTS

FIG. 2.—DIAGRAM OF CIRCUITS OF HIGH-TENSION TRANSFORMERS

on the clock dial appearing in the illustrations was used as a means of identification.

The tests were applied in the following order:

1. Dry test.
2. Wet test.
3. Parallel test, dry and wet.
4. Puncture test, under oil.
5. Mechanical test.

The Dry Test consisted of

a. Flash-over test on each section in order to exclude weak or punctured units.

b. Potential test on each complete insulator, also on smaller

number of sections. Voltage was applied and raised by succesive steps and photographic records were taken while the test was progressing.

Records were kept of the time on the clock dial which was set for each new test, voltage applied, time of exposure, number of sections, and such other observations as were made during the test which could not be recorded on the photograph.

In this manner, each type of insulators submitted was subjected to the same series of tests under exactly like conditions.

The Wet Tests consisted of applying rain at 45 deg., the precipitation varying from 0.25 to 0.35 in. (6.35 to 8.39 mm.) and finally to 0.53 in. (13.46 mm.) of water per minute. Accordingly each insulator was subjected to three series of tests, in which voltage and precipitation were the variable quantities. The execution of these wet tests was very similar to those of dry tests. Photographs were taken and records made of each test and observations were carefully noted.

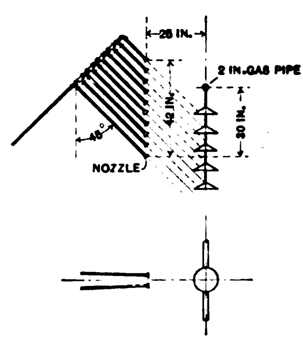


FIG. 3.—ARRANGEMENT OF NOZZLES FOR 0.53 IN. PRECIPITATION PER MINUTE

For these rain tests, which were the most important of all, the following method was adopted. A number of nozzles of the type used for spraying trees were secured to the ends of pipes cut to suitable length, and these, in turn, were connected to the water mains by means of a rubber hose and arranged to slide along a vertical post. Two groups of nozzles were used, and by means of this arrangement, it was possible to adjust the angle of precipitation, and by moving the nozzles closer or further away from the insulators, to adjust the amount of rain supplied per minute. It was found more expedient to entirely open the valve in the mains, thus operating with full pressure of the standpipe, and to regulate the amount of water by adjusting the number of working nozzles, their heights and distance away form the insulator under test. The amount of precipitation was determined by means of a specially constructed rain gage, consisting of a funnel-shaped vessel with a cover, provided with an aperture five in. (12.7 cm.) in diameter. The edges of the opening were slightly raised to prevent the water from spilling and splashing over the top of the funnel when striking it at an angle of 45 deg.

The gage was held in the rain at the points where the several sections of the insulators would be located, and the quantity of water was measured with a graduated glass. As a rule the gage was operated for four minutes and the fall of water determined from the amount gathered during that time. By setting the nozzles and adjusting the spacing, the correct amount of precipitation could be obtained and this setting was left undisturbed during each series of tests. One insulator after the other was moved to the mark on the pipe and voltage applied, beginning low and increasing by successive steps.

It was found that although water flowed freely over all the sections, wetting an area of 7 ft. (2.13 m.) in diameter, on the

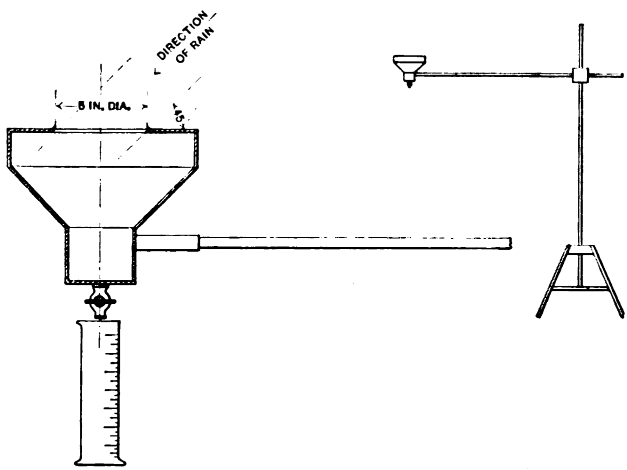


FIG. 4.—RAIN GAGE AND STAND USED FOR DETERMINING FALL OF WATER

platform, and thoroughly flooding the top of the sections, the inside of the insulators remained practically dry except for a few drops. For those reasons, it was necessary to apply the rain for some time before voltage was applied in order to arrive at reliable and unvarying results. The water was turned off when insulators were changed and turned on again when ready for test. A long series of check tests showed that the precipitation was constant within the error of observation after turning water on and off, provided the valve was always turned on wide open.

In most cases, the same underhung suspension insulators, strung horizontally, were subjected to a series of rain tests to ascertain their performance when used as strain insulators, but on account of this horizontal position, required a somewhat

different method of supporting. The insulator was strung between two well-braced upright wooden posts. In order to prevent leakage to ground, a number of units were inserted between the posts and the insulator under test. The nozzles, twelve in number, were located directly above at a distance of 25 in. (63.5 cm.) from the center of the insulators, directing the spray of water, which could be raised from 0.22 to 0.5 in. (5.58 to 12.7mm.) and even 0.75 in. (19 mm.) per minute at an angle of 45 deg. either toward the inside or the outside of the sections. The water was measured with the same rain gage used in previous tests, at eight different points within the space occupied by the insulator when in place, allowing the gage to remain thirty seconds in each of the eight positions.

Parallel Test. A most interesting series of tests with all insulators connected in parallel was made later in order to closely follow their performance simultaneously at different voltages. The insulators, composed of a proportionately smaller number of sections, were supported from the pipe, equally spaced, their lower ends connected by a common bus. Voltage was applied and gradually raised as in previous tests. As soon as a voltage was reached at which one of the insulators would show signs of distress, a photographic record was taken of the whole set after which the failing insulator was disconnected from the bus and the voltage increased until one of the remaining insulators would fail and so on. A similar series of tests was performed with the insulators subjected to rain. Each insulator had its own set of nozzles and the flow of water was regulated to be the same for every string. The test was made with 0.15 in. (3.8 mm.) of water per minute at 45 deg.

Puncture Test. Under ordinary conditions, it is almost impossible to puncture an insulator, in dry air, since a well-proportioned insulator will flash-over at a voltage well below its puncture voltage. To obtain values for the puncture voltage, it is necessary to immerse the insulator under oil and to take a number of other precautions, like the protection of leads, etc. Following this plan, a series of tests was performed in which this voltage was determined for all the different types of insulators.

Mechanical Tests. The testing device used to determine the the breaking strength of suspension insulators, consisted of a frame-work in which the insulator was fastened by links and steel cables and the tension applied by means of a screw acting on a lever. A robust dynamometer indicated the maximum pull

exerted by the screw and that pull multiplied by three, the ratio of the lever arms, gave the actual tension on the hook of the insulator. Voltage was applied across the insulator while pulling, but it was found that the insulator punctured always at the moment of fracture, so this method was discontinued on subsequent tests. A number of tests were made with each type to arrive at a fair average figure, and photographs were taken of the appearance of the fractures.

The above is a brief outline of the apparatus and methods used in making the tests on high-tension suspension and strain insulators. A number of post type insulators were also tested in a similar manner. As there were but two types offered neither of which met the specified tests, considerable development work was necessary until fairly satisfactory types were evolved.

After completion of all design tests and before the final selection of the insulator best fitted to fulfill the specified requirements, one week was set aside for witness tests. This was done to demonstrate to the manufacturers and their engineers the method which was followed in making these tests and to give them an opportunity to make their own observations with regard to the results obtained under conditions controlled in accordance with the tests specified. These conditions, as mentioned before, were kept unaltered during all tests and were constantly checked and adjusted, if this was found necessary.

The tests performed in the presence of the manufacturers were really nothing else but a repetition of the tests already made and incidentally, served the purpose of furnishing an additional set of confirming results. In every case, these results checked closely with those obtained during previous tests as the conditions under which, each test was made could easily be duplicated.

Test Results

SUSPENSION INSULATORS

As to the method of comparing the performance of the different types of insulators under test, it became apparent from the start that no standards existed which could be followed or used as a guide. From an academic standpoint it would, perhaps have been of importance to measure the watts lost for each type of insulator under varying conditions. This method may give results which would allow of direct comparison but the difficulty of measuring power accurately under the conditions imposed by the test, and at such high voltages appear to be out of proportion with the expected accuracy of the results. It was, therefore,

decided to compare qualitative rather than quantitative results. Under the assumption, which should not be far from correct, that the power loss of an insulator would make itself manifest in a proportionate display mostly of luminous character, the direct comparison of this visual display with the voltage required to create it should give a fair means of judging the relative insulating value of two insulators provided all other conditions remained the same and unaltered. In applying this method in practice, there are, of course, a number of other considerations requiring attention. For instance, the display of luminosity may appear gradually in direct proportion with the voltage applied, or it may appear rather suddenly after a certain limit of voltage had been reached; or else, the display may appear to be localized at some parts or points, which, though a portion of the insulators are of no value to its insulating quality and merely show faulty design. As will be explained later, the presence of such parts is always the cause of failure, regardless of the quality and design of the porcelain parts themselves. Taking into consideration the many sources which contribute towards the discharge of an insulator under potential and by following the system of comparison outlined above, it was possible to classify the insulators acording to certain well-defined merits and demerits. After balancing all merits of an insulator against all its demerits and by successively eliminating those insulators possessing the greatest number of demerits, it was possible to arrive at one type which had the least number of disadvantages and the most of the advantages.

In the discussion of the actual test results obtained, the different types of insulators are designated with the letters *A*, *B*, *C*, *D*, *E*, and *F*, in accordance with the half-tone illustrations representing the different makes. From the results of the dry test, it can safely be said that all insulators with the exception of types *A* and *B* withstood the tests of three times line voltage more or less satisfactorily. The following table gives the actual results in condensed form:

Type	Number of units	Brush discharge becomes visible at	Heavy static discharge but no flash-over
A	5	150 kv.	330 kv.
C	5	250 "	330 " on top
D	5	250 " on hook	330 " at point of hook
E	7	200 " on cotter-pin	Not excessive at 330 kv.
F	5	250 "	" " " "

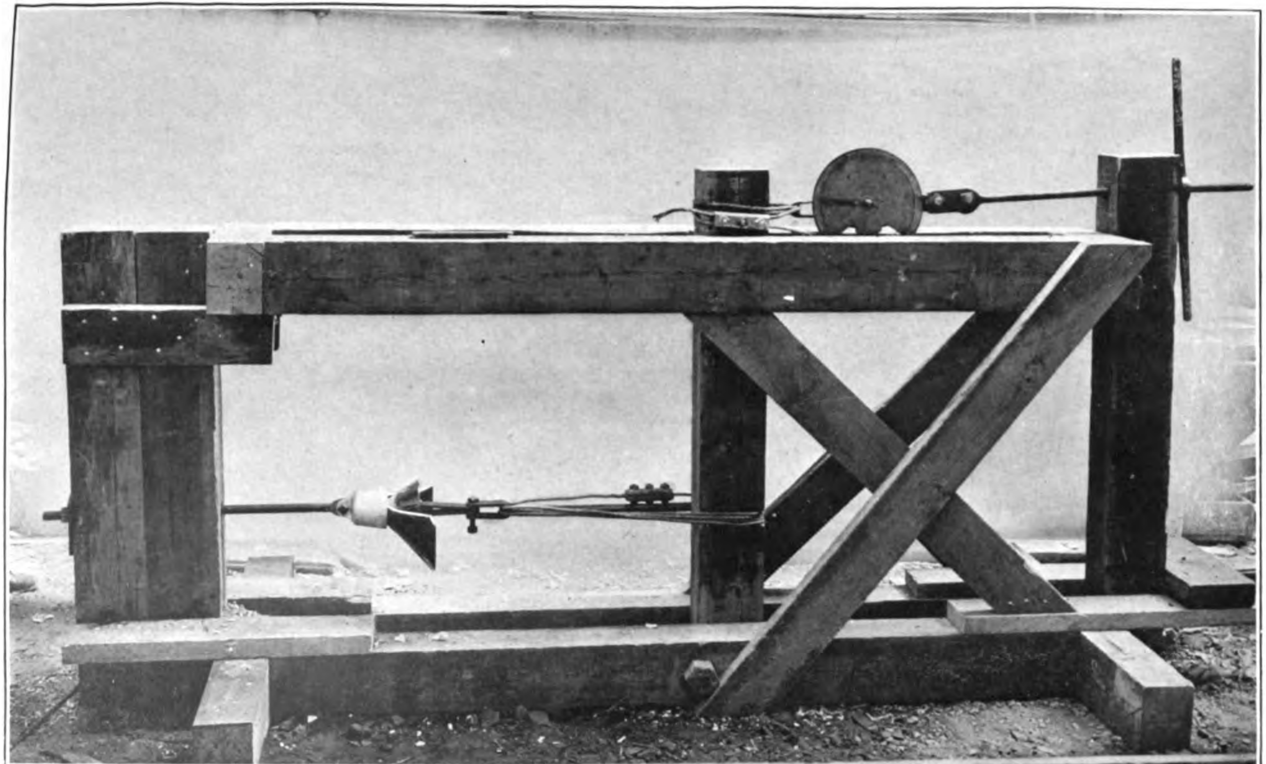
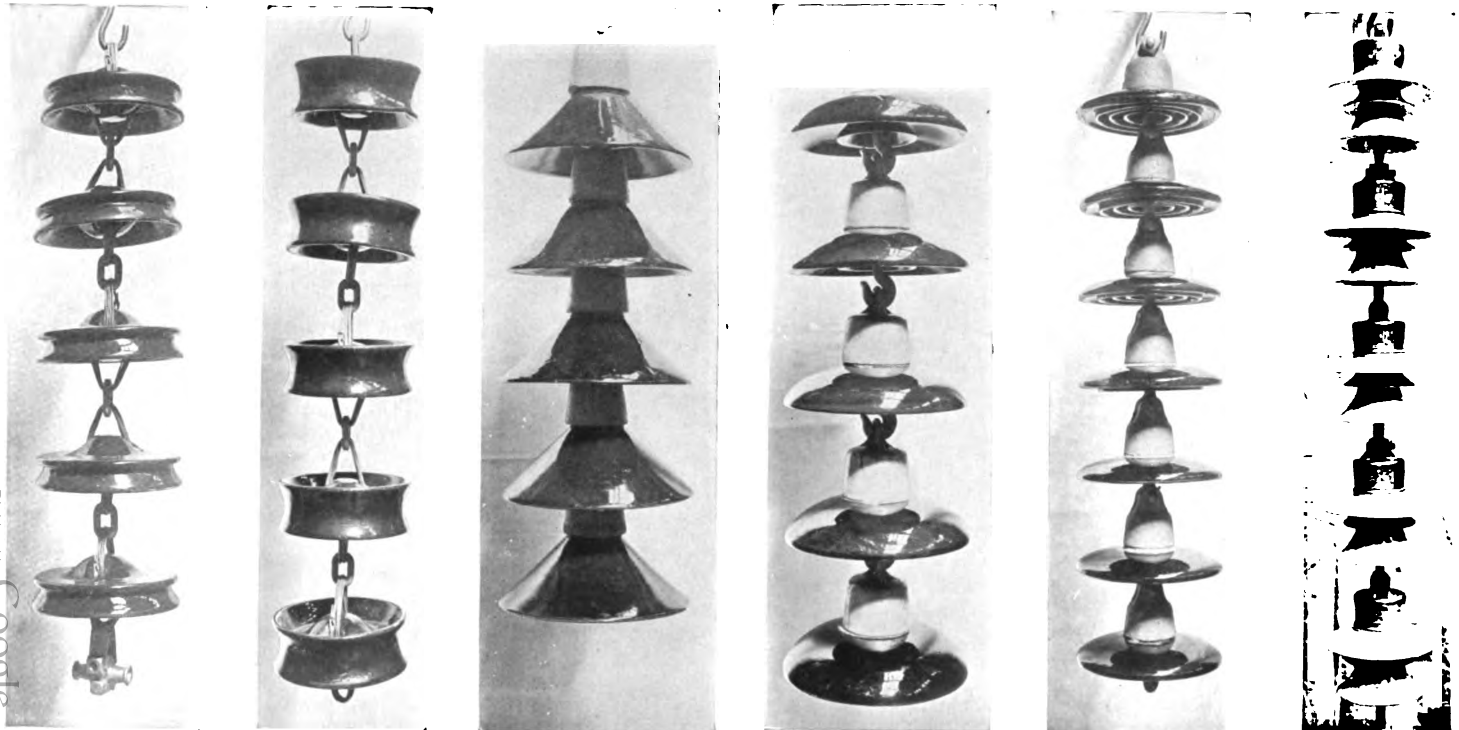


FIG. 6.—PULLING MACHINE FOR MECHANICAL TESTS [SOTHMAN]

Insulator section is fastened by means of cable and links to lever, operated by screw arrangement on the right—Dynamometer indicates maximum pull



Type A

Type B

Type C

Type D

Type E

Type F [SOTHMAN]

FIG. 7.—SUSPENSION INSULATORS SUBMITTED FOR TEST

Types A, C, D, E, and F are regular suspension Insulators—Type B is a proposed strain Insulator.

From the wet tests, which were the most significant of all, the final results of the series executed with 0.5 in. (12.7mm.) water per minute are given below:

Type	Sections	Discharge becomes visible below	Failure occurs at
A	5	150 kw.	160 kw.
C	5	225 "	265 "
D	5	250 "	280 "
E	7	225 "	260 "
E	8	250 "	300—310
F	5	250 "	300 "

The first visible discharge occurs invariably around the top section, in the form of streamers radiating in a more or less oblique direction away from the edge of the top skirt. The subsequent break-down of the insulator appears to grow gradually with increasing voltage. This is especially noticeable on type *A* whereas it is less prominent on other types; *i. e.*, they may hold out fairly well until a critical voltage is reached. Above this voltage, the insulator will fail rapidly with relatively slight increase of voltage.

As a rule, more or less active discharge always takes place around the pin of the inuslator within the hollow of the petticoat on all insulators designed along the orthodox lines of a pin insulator like types *C*, *D*, and *F*. This discharge is practically absent in the one-piece insulator *E* which is not provided with an inner petticoat. Any discharge which occurs at the point where the pin issues from the porcelain disk is effectively broken up and confined within a small, concentric corrugation.

The character of the break-down is different for each type of insulator. Type *A* breaks down on account of the excessive leakage; the whole insulator becoming conducting, as it were. The break-downs of the other types have more the character of a flash-over from one section to the next the moment the voltage is high enough to break through the wet and conducting air enveloping the sections. This break-down voltage could be ascertained with fair accuracy, and these figures were used as merits or demerits in accordance with their relative values.

From these records one feature is especially worthy of note. Almost in every case the discharge of the insulator was started

by a sharp corner or point of the metal fittings by means of which the sections were held together. In all cases except *A*, *B* and *D*, the static field around the insulator-sections was uniformly distributed in consequence of the almost symmetrically arranged parts occupying a space within this field. The word " almost " is used as the presence of even slight projections like the head of a cotter-pin in the bolt linking the two sections together was enough to break up the air at that point after a certain voltage was reached. In case *D* this phenomenon was particularly noticeable. The metal parts in the shape of two prominent hooks were so large that the field is excessively distorted creating highly uneven stresses in the air. The highest stresses are localized at the sharp point of the hook as is apparent the moment the voltage is raised above a critical value. That this distortion of the field is always accompanied by a premature failure of the insulator can be proved by eliminating those unsymmetrical iron parts, covering them, for instance, as was done in some experiments, with a cylindrical metal shield. Although the striking distance is thereby somewhat reduced, the insulator is capable of withstanding a voltage at least 10 per cent over and above that which it was able to withstand with the hooks bare. In case of *A* the distortion of the field is especially prominent. As beautiful as the link feature appears from a purely mechanical viewpoint, it creates most unfavorable stresses in the air between the disks, likewise in the holes within the disks. The stresses in the porcelain cap are more uniformly distributed in all cases except *A* and *B*. In these latter, the dielectric is strained the most at that point where the interlinking metal parts have their least separation from each other. In all other cases in which use is made of a metal cap and pin, the stresses in the porcelain are higher closer to the pin, and decrease gradually and uniformly towards the cap. As long as the highest value of this stress is well below the safe working limit the insulator is not endangered. But in every case, the diameter of the pin, together with the voltage it assumes, remain the determining factors for the highest stress of the porcelain within the cap. For this reason, it seems that no advantage is gained by the use of a two-piece insulator. Theoretically correct, the idea of using two thicknesses of porcelain would appear to offer a larger margin of safety. In practise, the idea cannot be worked out to its full efficiency for the size of the pin cannot be increased without correspondingly increasing the size of the cap, making an insulator of this sort too bulky and altogether impractical.

From all these considerations it was found advisable to have the metal parts of the insulators as symmetrical as possible, presenting a smooth and even surface void of any projection whatever. At one suggestion the ball and socket type connection was subsequently devised by one manufacturer to meet this contingency.

Another feature which militates against the use of a two-piece insulator is the fact that it is impossible to equalize the stresses in the two pieces under all and any conditions. In a dry condition, the porcelain of the inner petticoat is far less strained than when the top section is wet and conducting. The working efficiency of the material is bad and the cost of a two-piece insulator is necessarily high.

Outside of the design determining the electrical efficiency of the insulator, the method of mechanically connecting the different units to a string is of no little importance. The practise of cementing a pin into a porcelain shell and subjecting the pin to a strain may, at first sight, be regarded by many engineers as a doubtful proposition and it was in that light that the interlinking feature of types *A* and *B* was devised. As already mentioned, this link feature has proved to be a failure,at least electrically, and the cemented pin has so far given no cause for complaint. The breaking strength of the cemented pin on the other hand, had been found to be far superior to the wire link type, in some cases being nearly twice as strong. The device of type *C* is unquestionably a most splendid solution of the problem, as for an actual holding power, this type can hardly be excelled.

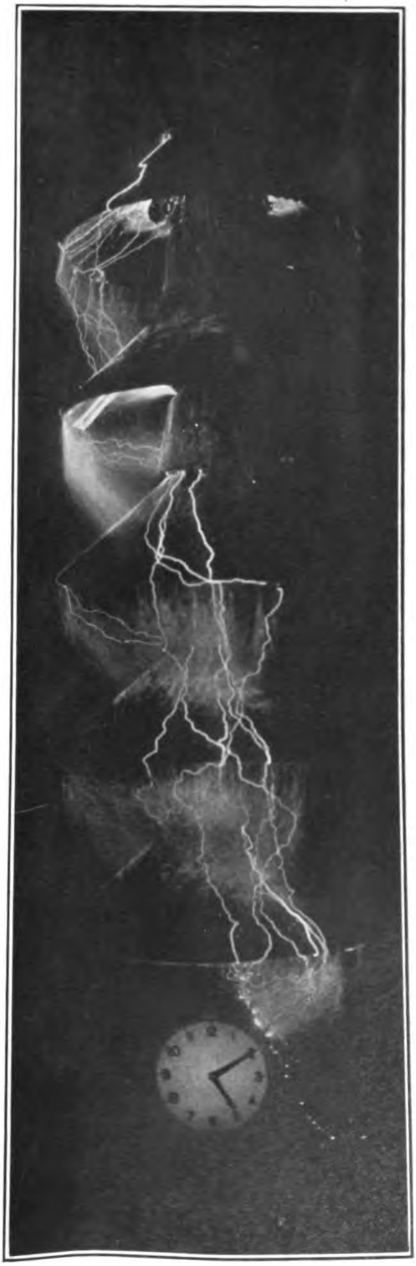
As stated elsewhere, it was possible to tabulate the test results and to classify the insulators according to their merits and demerits. How this was done will appear from the two following tables. The first table contains a summary of characteristics, *i. e.*, a tabulation of all features which can be measured and expressed in one or another unit. The first column of this table contains characteristics like diameter, spacing, number of sections, length overall, open spacing between sections, widths, etc. A number of other characteristics relating to design are also added, like number of pieces, method of connecting the sections, material, etc., and finally, characteristics bearing directly on their electrical efficiency, like leakage distance, thickness of shell, dry surface, etc. Opposite each column representing the actual figures corresponding to each type of insulator were placed certain comments, indicating observations or deductions with regard to those particular characteristics.

SUMMARY OF CHARACTERISTICS OF 110,000-VOLT SUSPENSION INSULATORS

Characteristics	Type *A*	Comments	Type *C*	Comments	Type *D*	Comments	Type *E*	Comments	Type *F*	Comments	Remark
MECHANICAL											
Size:											
Largest diameter.	10¼ in.		14 in.		14½ in.	Too large	10 in.		8⅞ in.		
Spacing.........	8 "		8 "	Too close	10 "		6 "		10½ "	Too far	Large number of sections of advantage electrically, not mechanically.
No. of sections...	5 "		5 "		5 "		7 "	good	5 "		
Total length.....	40 "		40 "		50 "		42 "		52½ "	Too long	
Open space between sections..	5 "	Small	5 "	Too small	8 "	Good	5½ "	good	6 "		
Weight:											
Per section (lb.).	9¾		22	High	24	Too high	10		12¾		
Total (lb.).......	48¾		110	High	120		70		64		
Strength.........											
Breakage in handling...........	None	Good	High	Very bad	None	Good	None	Very good	Low	Bad	
Mechanical design											Two piece insulator theoretically better than one piece but proper proportions are not obtained in practise. Should present perfectly symmetrical and smooth surface to prevent premature discharge ....
Number of shells.	One		Two		Two		One		One		
Cement used......	None		Portland		Portland		Litharge, also Portland		Alabaster plaster		
Connection between sections	Brass wire and links	Poor	*U* bolt and pin	Good	Drop forged hook	Bad	eye bolt & pin	Good	Eye-bolt & pin	good	
Renewal of sections..........	Difficult	Very bad	Simple		Simple		Simple		Simple		
Manufacture:											
Porcelain........	Bad		Good		Fair		Good & tough		Good		
Glaze...........	Rough	Bad	Rough	Bad	Glossy	Good	Glossy, poor finish	Fair	Glossy	Good	
Color...........	Chocolate		Brown		Yellow brown		reddish brown		White		
ELECTRICAL											
Design:											
Leakage distance per section....	11½ in.	Too small	24 in.	Good	20 in.	Good	13 in.	Sufficient	14½ in.	Good	
Dielectric thickness...........	1 × ¾ in.	Sufficient	2 × ⅝ in.	Sufficient	2 × 9/16 in.	Sufficient	1 × ¾ in.	Sufficient	1 × ⅞ in.	Sufficient	
Premature discharge......	None		None		Point of hook	Very bad	Point of cotter pin	rather bad	Practically none	Good	
Brush discharge appears	In and around cavities of porcelain	Very bad	Lower edge of cap and base of U-bolt		Base of hook and lower edge of cap		Lower edge of cap and base of eye-bolt		Between top and middle petticoat & base of eye-bolt		
Dry surface......	One flange	Poor	Petticoat	Good	Petticoat	Good	Three contric flanges	Sufficient	Two petticoats	Good	

FIG. 8a.—TYPE A—160 KV.—½ IN. WATER PER MIN.—45 DEG.

Under side of each section is flaming due to excessive leakage.



[SOTHMAN]

FIG. 8b.—TYPE C.—265 KV.—½ IN. WATER PER MIN.—45 DEG.

Breakdown of Insulator is consequence of flash-over—Note the point of discharge on left side of cap of second section.

FIG. 8c.—TYPE D—280 KV.–½ IN. WATER PER MIN.—45 DEG.

Breakdown of Insulator in consequence of flash-over—Note localized discharges from point and back of hooks.

[SOTHMAN]

FIG. 8d.—TYPE E—SEVEN SECTIONS—260 KV.–½ IN. WATER PER MIN.—45 DEG.

Breakdown of Insulator in consequence of strong leakage from section to section—Note discharges from points (Cotter Pins) on cap.

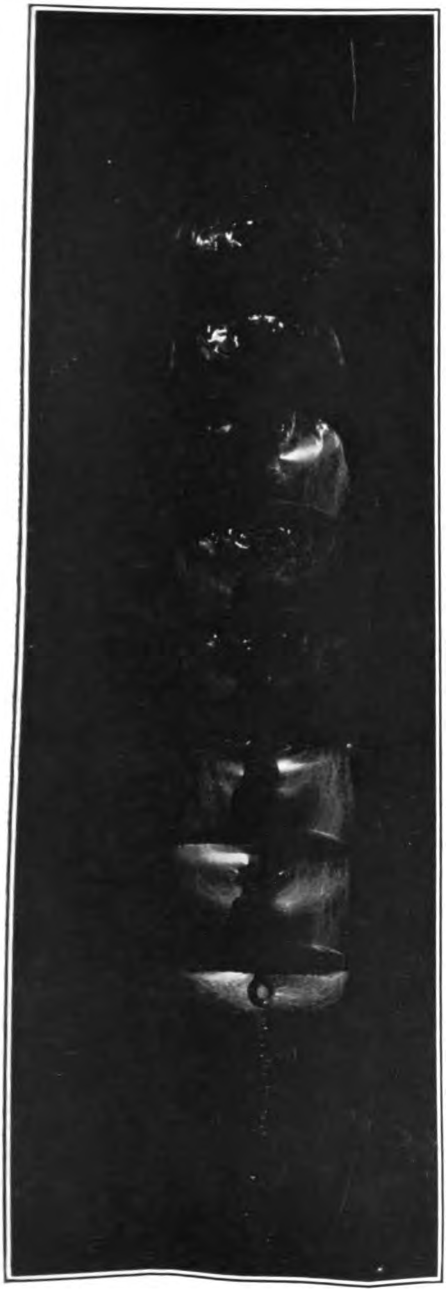
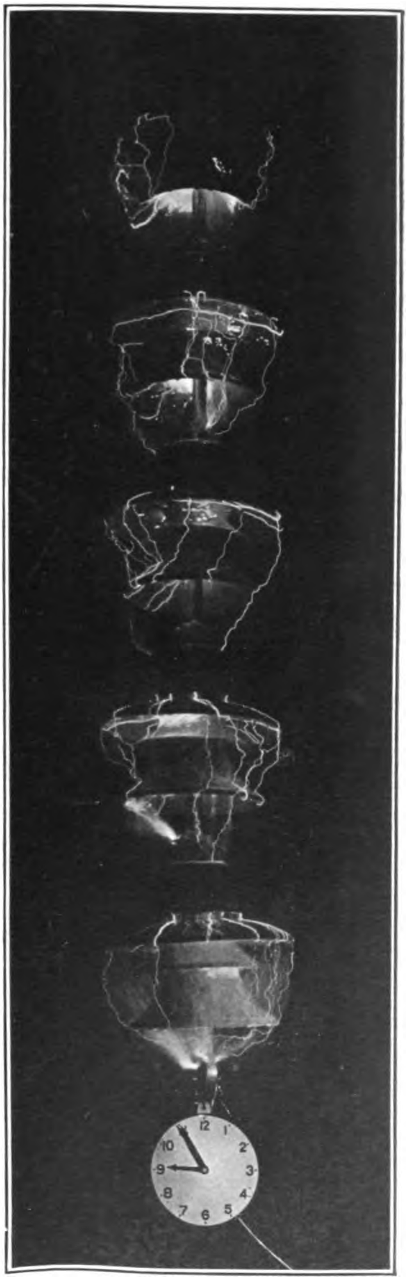


FIG. 8e.—TYPE E—EIGHT SECTIONS—310 KV.-½ IN. WATER PER MIN.—45 DEG.

Breakdown of Insulator in consequence of strong leakage from section to section—Note discharge from points (Cotter Pins) on cap.



[SOTHMAN]

FIG. 8f.—TYPE F—300 KV.-½ IN. WATER PER MIN.—45 DEG.

Breakdown of Insulator in consequence of flash-over from section to section—Note heavy firing inside petticoat in first and second sections—Also Point discharges (Cotter Pins.)

The second table is really a condensed statement of all results from actual tests, both electrical and mechanical. The table also contains the specification requirements. In compiling this table, a certain assumption was made which, although not absolutely correct, was justifiable in the light of the present comparison. For instance, in reference to the number of sections used, it was assumed that the share of line voltage per section was in direct proportion with the line voltage and number of sections.

According to the values given in the table, each section of insulator is subject to a voltage of approximately 22 kv. in all cases except in type *E* where this voltage drops to 15.7 and even 13.8 kv. per section, according to whether a complete insulator is made up of seven or eight sections, respectively. With the flash-over voltage per section known, the ratio of flash-over voltage to share of line voltage can be determined, this figure being equivalent to a safety factor against flash-over for the individual section. From the table it becomes at once apparent that type *E* has a very high ratio in comparison to type *A*, which has the lowest. Likewise, with the puncture voltage per section known, the ratio of puncture voltage to share of line voltage represents another safety factor against puncture which as in the former case, is the highest for type *E* and lowest for type *C*. The voltage per inch leakage distance has been found to be highest with type *A*, and lowest with type *C*, type *E* being next highest.

The table also gives the approximate percentage of sections puncturing. During the long run of the test it was found that insulator sections would puncture for no apparent cause and a record was kept of all these failures. At the end of the test it was considered of importance enough to compare these percentages with each other assuming that these values could be taken as a fair indication of the superiority of one insulator above the other, with reference to its dielectric strength. From the table it will be found that types *F* and *A* both had exceptionally high percentage of puncture as compared with the low percentage of type *E*.

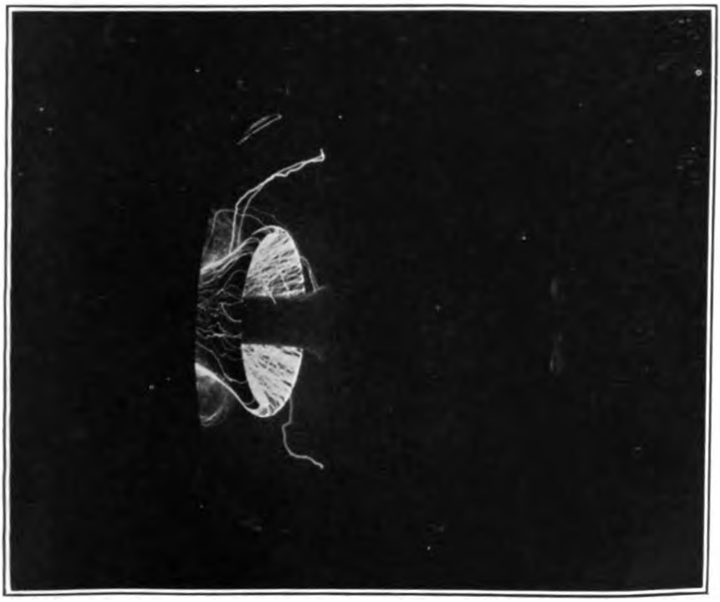
The average breaking strength of the different types of insulators as found from numerous tests are tabulated in the last-named table under "Mechanical Tests." The highest values were obtained with type *C*, the lowest with types *E* and *F*, all three types being cemented insulators. It must be said in de-

RESULTS OF TESTS ON 110,000-VOLT SUSPENSION INSULATORS

	Specification requirements	Type *A*	Type *C*	Type *D*	Type *E*	Type *F*
MECHANICAL						
Strength:		lb.	lb.	lb.	lb.	lb.
Breaking strain	8000 lb.	Average 9430	14000	10700	7650	7200
		Lowest, 8700	9600	7800	5100	5100
		Highest 10200	16200	12600	10800	8700
ELECTRICAL						
Dry tests:					7 sections 8 sections	
Share of line voltage per section		22 kv.	22 kv.	22 kv.	15.7 kv. 13.8 kv.	22 kv.
Flashover " " "	3 times share of line voltage	65—70 kv.	85 "	90 "	75—80 kv.	105 "
Puncture " " "		135 "	130 "	above 140 kv.	135 kv.	above 135 kv.
Approximate per cent of sections puncturing		75 per cent	33 per cent	30 per cent	10 per cent	85 per cent
Brush discharge becomes visible below (on complete insulator)		150 kv.	225 kv.	250 kv.	225 kv. 250 kv.	250 kv.
Ratio flash-over voltage to share of line voltage (safety factor)		3.0	3.8	4.1	5.0 5.7	4.75
Ratio puncture voltage to share of line voltage (safety factor)		6.1	5.9	6.5	8.6 9.7	6.1
Voltage per one in. leakage distance in kv.		1.9	0.91	1.1	1.2 1.06	1.5
Wet tests:						
(One-half in. water per minute at 45°, complete insulator.)						
Failure at approximately		160 kv.	265 kv.	280 kv.	260 kv. 300 kv.	300 kv.
Nature of failure		Excessive leakage	Flash-over	Flash-over	Flash-over and leakage	Flash-over
Flashover occurs		Gradually	Suddenly	Suddenly	Sudenly	Suddenly
Recommended working limit	220 kv.	80 kv.	200 kv.	220 kv.	200 kv. 225 kv.	225 kv.

[SOTHMAN]

FIG. 9a.—TYPE D—ONE SECTION AT 117 KV.
Note dischage localized at point of hook.



[SOTHMAN]

FIG. 9b.—SAME SECTION (a) AT 117 KV., BUT WITH HOOK PROTECTED BY BOTTLE-SHAPED METAL SHIELD.
Note absence of static over top umbrella, but strong discharge over petticoat.

[SOTHMAN]

FIG. 10*a*.—TYPE D—FIVE SECTIONS—280 KV.—½ IN. WATER PER MIN.—45 DEG.

Note discharge localized at point and back of hooks.

FIG. 10*b*.—TYPE D—SAME AS PREVIOUS TEST (*a*) EXCEPT HOOKS PROTECTED BY BOTTLE-SHAPED SHIELDS

Note absence of distress.

[SOTHMAN]

FIG. 10c.—SAME AS PRECEDING TEST (b) EXCEPT VOLTAGE RAISED TO 300 KV.

Note uniformly distributed discharge.

fense of the last two types, that subsequent tests on regular stock insulators showed a breaking strength of not less than 8000 lb. (3628 kg.), the relatively poor results obtained by the former tests being due solely to the cement which had not properly set.

From all observations and test results, the following conclusions were drawn up on which a classification of the various types of insulators in the following order, was based:

1. *Type F.* This type meets electrical requirements but not the mechanical tests. Design, however, can be readily modified to meet mechanical tests and incidentally, improve the insulator electrically. Percentage of puncture can be kept down by rigid inspection. Insulator shows high class workmanship and material.

2. *Type E.* This type meets electrical tests with eight sections but not the mechanical tests. Insulator should, without material modification of design, be able to come up to the required mechanical tests. Slight increase in diameter should also increase electrical efficiency of insulator. Large number of open spaces between units are of advantage. Insulator is strong, durable, light and compact. Method of connecting units should be modified so as to present symmetrical and smooth surface to prevent premature discharge.

3. *Type D.* This type meets electrical and mechanical tests. Insulator has, however, very faulty design. Diameter too large; weight and bulk too high. Inefficient cementing of hook. Hook feature to be condemned causing distortion of field and premature discharge. As a two-piece insulator electrical stresses of petticoats are not balanced.

4. *Type C.* This type meets the mechanical but not electrical requirements. The insulator is far too fragile, causing excessive breakage in ordinary handling. Sections are too close upon each other leaving too small a clearance between units. As a two-piece insulator, electrical stresses of petticoats are unbalanced.

5. *Type A.* This type meets mechanical but not the electrical requirements.

Final selection of the type *E* insulator was made in consequence of various favorable considerations. Type *F* is of European design and manufacture, and its selection would have entailed several difficulties, especially in regard to delivery. Next to type *F*, type *E* was found to be the most suitable and practical insulator, both from an engineering and a commercial point of view, and this consideration, together with the outlook for better

deliveries determined its adoption. It must be mentioned that the diameter of the insulator was subsequently changed from 10 in. (25.4 cm.) to 11 in. (28 cm.), and that the ball and socket type connection was universally adopted.

STRAIN INSULATORS

No special insulators were offered for use as strain insulators excepting the one designated as type *B* which is but a variation of type *A*. In order to increase the efficiency of the suspension insulator for use as a strain insulator, one or two additional sections were added by the manufacturers. From numerous tests similar in character to those performed on suspension insulators, it was found that none of the different types recommended by the manufacturer met the requirements of the specifications for wet test. Excessive leakage at voltages below the standard fixed in the specification (220 kv.) made their use as strain insulators prohibitive. As one exception, type *E*, using as many as ten sections instead of seven, showed some advantage over the others, but even at its best was found to be not entirely satisfactory. In every case failure of the insulator did not occur suddenly, but very gradually. Distress begins to be visible at voltages as low as 110 kv., this distress increasing in almost direct proportion with the voltage.

After considerable experimenting with new designs and numerous combinations, it was found that the use of ten sections of the adopted insulator type *E* gave the least unsatisfactory results of all. With a modification of the design of the cap, increasing the breaking strength of the insulator, this type was finally adopted for use as strain insulators.

The preceding sections of this paper dealt with the investigation only in so far as it covered the selection of a suitable insulator. With this question settled, there remained one not less important part of the work, viz: the supervision of the factory tests on some 140,000 insulator sections. The specifications called for distinct electrical and mechanical tests on each unit, and the acceptance of the insulators was based on their ability to pass these tests. Outside of these specified tests, the insulators had to conform to certain well-defined standards as to shape, quality, finish, etc. The whole inspection and supervision of tests was comparable to a weeding-out process, and it was the duty of the inspectors to see that this process was carried out in conformity with the specifications. After successful completion of all factory tests,

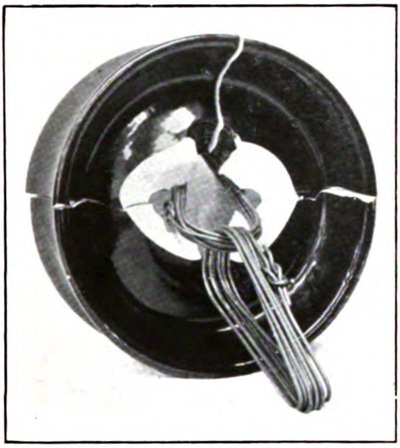
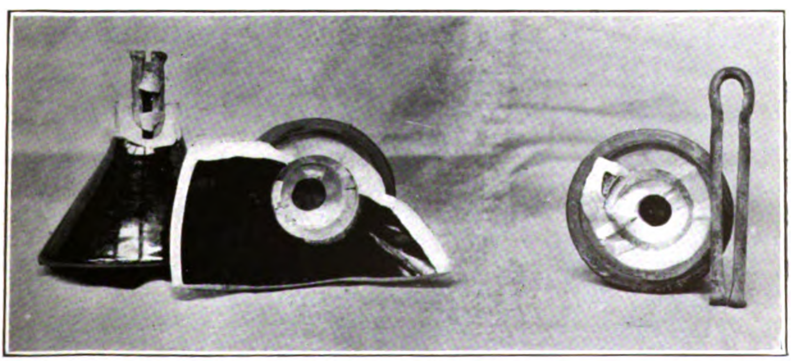


FIG. 11*a*.—TYPE B—FRACTURE OCCURRED AT 8000 LB.

[SOTHMAN]

FIG. 11*c*.—TYPE D—HOOK PULLED OUT AT 9000 LB.

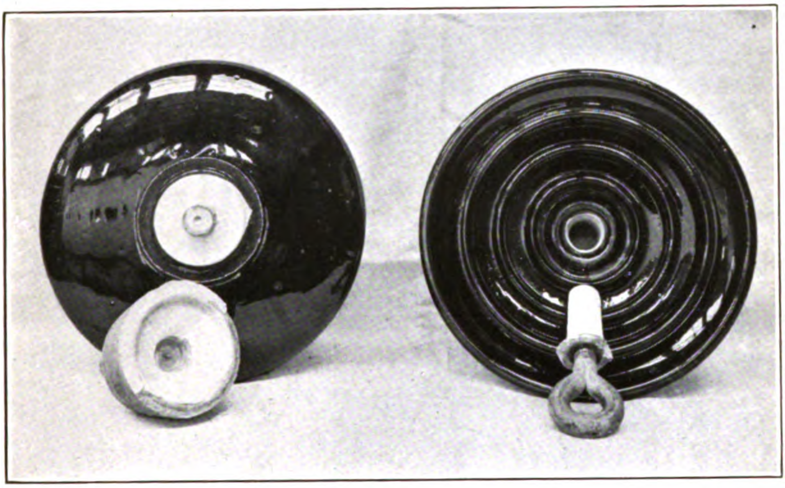
Poor mechanical design-holding power of hook reduced to the shearing strength of cement.



[SOTHMAN]

FIG. 11*b*.—TYPE C—FRACTURES OCCURRED AT 15,000 LB.

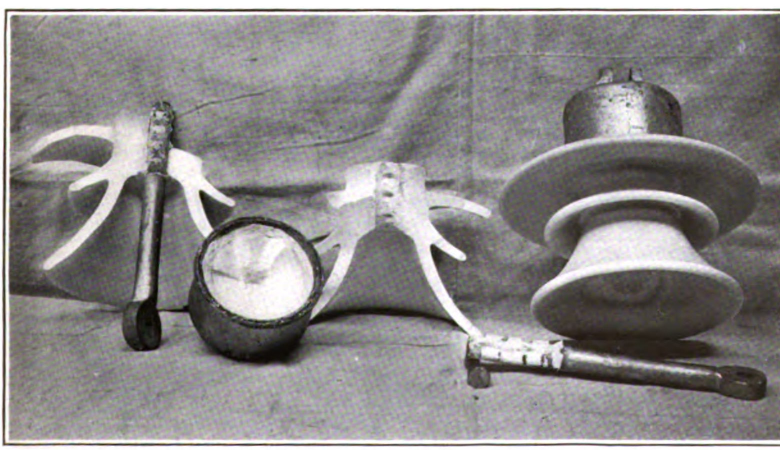
Note distortion of U-shaped eye-bolt indicating excellent holding power of construction.



[SOTHMAN]

FIG. 11*d*.—TYPE E—FAILURE OCCURRED AT 7500 LB.

Note sound fracture—eye-bolt pulled out at 10,800 lb. The latter was cemented with Litharge and Glycerine which had remained soft.



[SOTHMAN]

FIG. 11*e*.—TYPE F—AVERAGE BREAKING LOAD 6900 LB.

Holding power of lips cut in eye-bolt very limited—Plaster of paris not suitable for cementing.

the insulators were packed and shipped to the nearest railroad siding where they were delivered to the contractors.

Even though the specifications were drawn up with the utmost care, taking into consideration every phase of the work involved, it was found during the course of this investigation, and especially during the subsequent work at the factories, that they did not meet every contingency. In a number of instances it was found almost impossible to hold the manufacturer down to the terms of the specification, but that he had to be allowed a considerable margin in his favor. Although the manufacturer guaranteed to furnish insulators in accordance with samples submitted and approved in the regular course of manufacture it was found to be a commercial impossibility to keep the standard at par with the hand-picked samples. In prescribing limits between which variances were allowable, both mechanically and electrically, it proved to be a very difficult matter to draw a distinct line. After the contract was let and the manufacture was progressing, difficulties were encountered in determining when an insulator had successfully passed certain inspection or tests, requiring several conferences between manufacturer and engineers in order to come to a definite understanding. From all these experiences and observations, it was found that specifications for high-tension insulators were susceptible to a number of amendments, which, if properly worked out, would go far towards minimizing possible misinterpretations and misunderstandings.

In viewing this work now, after a number of years rich in experience have passed, and in the light of all after events, it must be admitted that the problem of insulating high-tension transmission lines is yet far from being solved. Much valuable experience has been gained which, in the course of time will undoubtedly be utilized to improve methods and means of effectively insulating and protecting a transmission line. With special reference to the question of insulators and their future development it will be understood by all that work in this direction can be carried out successfully only with a close co-operation between the ceramic and operating engineers. The question of properly designing and loading an insulator is one which presumes a thorough knowledge of transient phenomena occurring on a transmission line and their proper interpretation with regard to the effect on the insulators. Once these phenomena are known and their effect thoroughly understood, the drawing up of speci-

fications for high-tension insulators will become a matter less open for conjecture. For it is quite probable that precautions, now taken in one direction, are often unwarranted and uncalled for, whereas, on the other hand, liberal allowances made in other directions may be of the greatest detriment to the line and insulators.

In summing up the experience gained during the foregoing investigations, especially with regard to testing, the following points are presented as worthy of future consideration and discussion:

They are given in the form of an itemized list of headings or questions to which are added a few remarks, commenting on certain experiences gained either in the field, in the factory, or in the testing room.

Design Test.

What design test should be specified for insulators intended to work at a certain voltage?

In the present case a dry test of three times line voltage was specified. Experience, however, seems to indicate that even though the insulator may meet this arbitrary condition, its safety against failure in actual operation is not thereby assured. It is a well-known fact that an insulator is never endangered by the steady static forces but rather by those sudden and transient movements appearing in a system and caused either by external or internal disturbances. It is not the steady dead-load which is dangerous to a bridge or structure, even though it may assume a value two or three times higher than the load for which it was designed, but those moving loads which will set up vibrations and surges in the structure, especially if they are rhythmical in character and coincide with the natural swing of the bridge. For this reason, soldiers are generally not permitted to cross a bridge while marching in step. Although the actual forces coming into play are insignificant in such cases, their effect may, under certain conditions, become disastrous. It is without doubt that the insulators of a transmission line are very susceptible to similar phenomena, and to guard against failure from these causes, it will be necessary to impose tests of an entirely different character.

Method of supporting insulator during test. Should insulator support be grounded and voltage applied to groove, or should voltage be applied between groove and pin, both ungrounded?

At first sight, it may appear as if the manner in which the insulator is supported during tests is of no importance. As a

matter of fact, the proximity of large grounded or ungrounded bodies close to the insulator under test will materially affect the distribution of the static field around the insulator, especially when these tests are performed with one side of the potential grounded; the best method of supporting an insulator and applying a test would undoubtedly be the one which closely approximates conditions under which the insulator works in actual operation.

> Capacity of testing transformer and generator. Method of regulation of voltage. Determination of correct voltage during test at any time. Should spark gap be used or static voltmeter, or should step-down transformers in connection with voltmeters be used?

The kilowatt capacity of the testing outfit cannot be too large, for the puncture of a weak insulator may never be discovered but for the power back of the transformer.

As to the method of regulating the voltage: It must be accomplished by means which do not alter the shape of the alternating current wave form and the latter should be a true sine curve. From the different means employed today, like water rheostat, induction regulators, auto-transformers, etc., the method of regulating the voltage of the alternator by controlling its field current seems to offer the most advantages.

In reference to the determination of the voltage, several methods are at present in vogue. The most common of these methods involves the use of a properly calibrated spark gap. An ordinary voltmeter in connection with a step-down transformer is also used, and finally, in some instances, static voltmeters have given excellent satisfaction. Each of these methods, however, has its drawbacks. The spark gap setting is susceptible to atmospheric conditions. It may also introduce undesirable oscillations at the instant of discharge. The breakdown voltage of an insulator cannot be determined by means of spark gap alone, which in this case, must be supplemented by a voltmeter reading. Another feature, is the burning off of the points, each time the gap discharges, a matter which cannot always be avoided. The method employing stepdown transformers is not altogether reliable and should be used in connection with a gap from which the voltmeter readings are calibrated. Undoubtedly the best method to ascertain the value of the testing potential is by means of a static voltmeter of suitable design.

Frequency, permissible distortion of wave form, effect of harmonics and high frequencies.

The effect of the frequency upon the results is a matter which is very seldom fully appreciated. The value of the charging current increases in direct proportion with the frequency, and the effect of this current will naturally follow a similar law. An insulator tested at 60 cycles will show different results than when tested at 25 cycles, the potential being the same in both cases. If for any reason, the wave form of the alternator is not a true sine curve, the results may become extremely misleading, to say the least. In one case which is on record, a porcelain transformer bushing was tested at two different places under apparently identical conditions, and yet the results differed by nearly 40 per cent. The tests were checked and repeated several times with no better results until finally, the wave form of one of the alternators was found to have a very pronounced 13th harmonic. Immediately this harmonic was suppressed, the tests could be duplicated at both places without difficulty. The smaller the number of insulators tested, the smaller also the capacity of these insulators, the more pronounced will be any effect caused by higher frequencies appearing in the electrical system used for such tests. With a large number of insulators, and consequently, with a large capacity available, these higher frequencies will cause relatively little trouble provided the amount of energy they represent is small. But in all cases where the capacity of the insulator tested is small, the wave form of the alternating current should be a pure sine wave.

As to the number of insulators which should be tested in order to arrive at a fair average value, this is a matter left open for discussion.

Effect of power factor upon test.

The effect of the power factor on insulator tests is also left open for discussion. When a large number of insulators are tested simultaneously, the available load of the transformer is utilized to charge that large capacity and there will exist considerable lead between this charging current and the impressed e.m.f. Whether or not this power factor has any influence on the test results is left open for discussion.

What wet test should be specified? Should it be artificial rain, dew, salt water spray, etc.? Amount of precipitation per minute? Character of precipitation and means for applying the same? Angle at which this precipitation should be applied?

Several means for approximating the conditions found in the open air are used at the present time. Artificial rain is applied which may vary between wide limits from a downpour to a mist, it may be applied vertically or at an angle, usually 45 deg. Or else, the insulators may be confined within an air-tight room in which steam is left to escape until the insulators are completely enveloped in an atmosphere of steam and covered with a film of condensed vapor. Each test will yield certain results but no two tests can be compared unless the conditions governing the tests are the same in both cases. Which of these methods is the most effective one remains to be determined. It should always be chosen with regard to the facility for duplicating it at any time. In the present instance, the specifications called for 250 kv. with 0.5 in. (12.7mm.) rain per minute vertically applied, or 220 kv. applied at 45 deg. These figures may seem arbitrary, and far above the standards commonly used, but on the other hand, they also include a safety factor higher than it is customary to allow. The above rain tests are easily made or duplicated, which is a great advantage. On the other hand, the distribution of the water needs considerable improvement to approximate more closely real rain.

> What should determine the failure or the success of insulator under test? Should it be the luminous display when test is performed in absolute darkness, and if so, what should be the limit of intensity? Or, should the ratio of flash-over or breakdown voltage to voltage at which first sign of luminosity appears, be considered?

With all conditions of test fully determined, and agreed upon, there remains the most difficult task of all; namely, to judge the performance of the insulator under test. The method followed and described elsewhere in this paper was the only one which promised to yield comparable results. This method, however, has the disadvantage of being a purely subjective matter. Even the comparing of photographic records is susceptible to that personal element always present. That the method is not free from objections has been realized from the start, but in the absence of some better way, it had, at least, the advantage of simplicity. It is quite evident that there must be other ways of determining the efficiency of insulators than by merely comparing their luminous display either among themselves or with that of a standard. What this method should be, is an open question. Undoubtedly, the determining of watts lost would yield results free from the personal element if a reliable method

could be devised. In regard to the other method mentioned, in which the ratio of breakdown voltage to voltage at which first brush discharge becomes visible, is made the basis of comparison, it is likewise not always an easy matter to determine the exact value of this voltage. The breakdown voltage of an insulator, as a rule, is fairly constant but the voltage at which the brush discharges become visible depends largely upon various accidental conditions and eventualities which render its determination extremely difficult. Consequently, this method should be viewed with the utmost caution.

Puncture Test.

Method of applying and performing test. Method of applying electrodes. Number of samples to be tested in order to arrive at a fair average value.

As a well-proportioned insulator will flash over before its puncture voltage is reached, it becomes necessary to test the insulator under oil. In this test, the most important feature is the application of electrodes. Unless the area presented is of sufficient size, erratic and unreliable results are obtained. The cemented cap and pin of sections of the suspension-type insulator form ideal electrodes in a test of this character, inasmuch as they distribute the stresses in the porcelain evenly and uniformly, also in exactly the same manner as obtains in actual use.

Mechanical Test.

What should this test be? Method of subjecting insulator to mechanical test according to whether pin insulator, suspension and strain insulator is tested. Method of applying load. Method of recording load at any instant. Should mechanical test be performed with insulator under voltage?

Routine Test and Inspection.

Inspections for physical defects. What are the limits to be observed in rejecting insulators on account of mechanical imperfections?

There naturally exists considerable difference of opinion between manufacturers and engineers as to the insulators which should be rejected. In most instances, the porcelain manufactured in this country will show an imperfect surface. This imperfection is caused by warping of body, discoloration, small cracks, flaws, grooves and foreign material adhering to glaze, bubbles underneath the glaze, etc. As a rule, foreign and especially German porcelain is faultless in those repects and there is never the slightest difficulty in rejecting insulators in these factories.

What routine tests should be specified? Method of applying such tests. Number of insulators tested simultaneously. Method of applying voltage. Should these tests be continuous or should test be executed in stages, allowing for the removal of insulators failing during test? If insulators are subjected to time test, should the test be continuous? Is it good practice to subject insulators to flash-over test for any length of time with regard to possible deterioration or fatigue of the porcelain? What conditions will determine the success or failure of test? Should insulators failing be cut off automatically from the rest of the insulators under test?

Two-Piece Insulators.

Where insulators are made up of several parts, cemented together, should cement preparation and method of cementing be specified? Length of time allowed for setting? Should insulator be tested over electrically after cementing is done?

Considerable difficulties were experienced in Germany with cemented insulators. The cement used in that country is either plaster of paris prepared in a special way, or litharge and glycerine and several other cements of secret composition. It has been found that after some time, the shells would crack, due—as was inferred—to the working of the cement used, and for that reason the cemented type insulator has been abandoned in favor of the single-piece type.

While the insulators which were selected as a result of these tests have proved to be highly satisfactory throughout a peroid of two years' operation, there have been nevertheless a few characteristic failures. In most cases the ultimate failure of these insulators was due to puncturing, although there exists strong evidence that this failure was preceded by the cracking of the petticoats through no apparent cause. In most cases when puncturing takes place, it affects all sections of the insulators with the curious but nevertheless logical result that holes are burned through the insulator cap opposite the point of puncture in the porcelain and fusing the metal surrounding it. The size of the hole in the cap depends to a great extent upon the time setting of the circuit breakers at the power station. If the circuit breakers trip out instantaneously after puncture has occurred, there may be no burning of the cap whatsoever. On the other hand, if the circuit breaker holds on for three or four seconds or even longer, the current to ground, which is limited through a resistance of large heat capacity connected between the neutral point of the transformers and ground, fuses the porcelain and adjacent metal parts. In one of these cases, where the hoels

through the caps are quite large, the circuit breaker did not trid out at all and one of the insulator sections under the excessive heating action of the current to ground finally came apart, thus automatically interrupting the circuit.

It is a rather difficult matter to determine the primary source of these failures. It may be due to cracks in one or two of the sections, which naturally tend to greatly lower the total insulating capacity of the insulator. If then, during a lightning storm, or during switching, surges are set up in the line, the weakened insulator becomes punctured as a direct result of any discharge occurring in the vicinity along the line. Considering the large capacity involved in the system and the power back of the transformers, this localized discharge in the insulator may immediately set up powerful commotions and oscillations which may effect the adjacent insulator and finally puncture one after the other in rapid succession.

The cracks inside the insulator cap and also the falling apart of the insulator sections with no apparent cause may have been due to faulty insulators having accidentally passed inspection, or it may have been brought about by the subsequent expansion which takes place in the cement within the cap and around the pin. This cracking of the cemented insulator has been experienced in Germany, as mentioned elsewhere in this paper, although in these cases the insulators in question were pin insulators only. It is almost impossible to determine whether the cracking of the porcelain within the cap is actually due to the uneven expansion of the porcelain, cement, or metal cap under temperature changes, or whether they were a result of the puncturing of the insulators. The inspection of some 140,000 sections of insulators was a task requiring much endurance and although the work was carried out with great conscientiousness, it is quite possible that a few sections with a weakness in the porcelain cap which would not be detected by the ordinary rountine test, may have passed by. There is also to be considered the theory of electrical and mechanical fatigue in the porcelain and cement respectively, which has already been discussed by several authorities. There seems to be no doubt that some such effect takes place but the data which has been collected so far on the subject is not sufficient to permit of definite conclusions being drawn. To be able to insure absolutely continuous service over any transmission system may necessitate the sectionalizing of the line where each section can be periodically tested at much

higher voltage or else it may be necessary to remove the insulators in batches and test them individually as has already been done by one of the large operating companies.

At the present time there appears to be a rather unwarranted competition by the different manufacturers and operating companies to use excessively high voltages. There is a system already in operation at 145,000 volts and quite recently another company has contemplated the use of 180,000 volts. In view of the fact that operation at 110,000 volts has not yet reached a stage of maturity, and the fact that phenomena which were not anticipated, occur on such lines, and which, even now, are far from being fully understood, considerable caution should be displayed before attempting the use of still higher voltages. A few years ago the suspension type of insulator was heralded as the solution for line insulation up to any voltage at which it would be practicable to operate for many years to come. The factor limiting the use of high voltages so far as the line was concerned was then considered to be the effect of corona and leakage into the atmosphere. But from past experience it is almost certain that these views will need revision and that a systematic and thorough study of the properties of insulators is urgently required.

Examples of the rather uncertain conditions manifesting themselves in a high-voltage power transmission system are mainly the behavior of oil circuit breakers when large amounts of power have to be handled, the lightning arrester problem, and even the high-tension transformers. Most all of this apparatus, as will be admitted by the manufacturing companies, is yet in the stage of development, and it is very gratifying to see that a large amount of study is being devoted at the present time to render these devices more reliable in service.

The above criticism should not be taken as an indication of extreme conservatism or as tending to block the way to progress, but under the prevailing conditions, it is almost imperative that a word of caution should be spoken to prevent the somewhat extravagant use of the higher voltages when the use of lower voltages would answer the purpose equally well, and especially when the difficulties which are encountered with these extreme voltages may endanger the financial prospects of a particular power proposition.

I cannot close this paper without mentioning the Ontario Power Company at Niagara Falls, in whose plant these tests were made. The president of the company, Mr. J. J. Albright,

and vice-president, General F. V. Greene, and their engineer in charge, Mr. V. G. Converse, have given their heartiest support and assistance to the furtherance of this work in gratuitously supplying all necessary testing equipment, power and the help of their personnel for these tests. I welcome this opportunity to personally and publicly thank these gentlemen for the interest they have taken in this work, for their generous help and friendly cooperation.

HIGH FREQUENCY TESTS

OF

LINE INSULATORS

BY

L. E. IMLAY and PERCY H. THOMAS

Presented under the auspices of the

High-Tension Transmission Committee

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HIGH FREQUENCY TESTS OF LINE INSULATORS

BY L. E. IMLAY AND PERCY H. THOMAS

The object of this paper is to present for consideration certain very interesting and suggestive high frequency insulator tests recently made by the authors. These tests were undertaken to determine the availability of a certain insulator for use on a projected 38,000-volt line and resulted in a radical modification of the design. Having a strictly utilitarian purpose in view, these tests were not expanded to a point that would be desirable from a scientific point of view, although the nature of the results shows the great desirability of further research in this same field. With this explanation the plan of the tests will be understood.

A certain transmission system* has used three parallel circuits operating at 22,000 volts to transmit a rather large amount of power over some 16 miles for a number of years. The demand for more power has rendered a new line necessary, which is being installed for 38,000-volt operation. The insulators on the old lines are made of electrose having an umbrella petticoat about 12 in. (30.4 cm.) in diameter, and a second smaller petticoat about 6 in. (15.2 cm.) in diameter. They were originally intended to be used on 38,000 volts when the rise of the load should require. Experience showed that these insulators occasionally punctured through the head from lightning, such failures being very difficult to find. The insulators are mounted on grounded steel pins. This sort of failure was very surprising in view of the fact that these insulators had never been punctured in testing, though they would arc over when wet at about 90,000 volts, as indicated on the primary side of a 25-cycle testing transformer.

It was this discrepancy between the repeated punctures

*Canadian Niagara Power Co.

through the head from the conductor to the pin due to lightning, and the steady refusal of the insulators to puncture on a 25-cycle testing set, that led to the high-frequency, high-voltage tests described below.

These tests were made to determine directly whether any difference in the behavior of the insulators could be determined between the use of high frequency and 60 cycles, both produced in the laboratory.

The circuits for the high frequency tests are shown in Fig. 11.

In this figure is indicated a 500-kw., 750,000-volt transformer. One side of this transformer is grounded and the other side connected to the discharge apparatus. The "plate" shown was a sheet iron plate approximately eight by nine ft. (2.4 by 2.7 m.), estimated capacity 0.0001 microfarad, suspended by a cord approximately 3.5 ft. (1.06 m.) from a large transformer tank, which served as a ground pate. The coils marked *A*, *B* and *C* were three air-core choke coils intended to protect the transformer. The coil *A* was a helix having a diameter of 18 in. (45.6 cm.), and had approximately 22 turns of wire, the turns being spaced approximately three in. (7.6 cm.) apart. The coil *B* was circular and approximately 24 in. (60.9 cm.) in diameter and had 10 turns. The coil *C* was a pancake coil and had approximately 200 turns with a mean length of turn of 37.7 in. (95.8 cm.) This coil *C* was shunted by a graphite resistance of about 125,000 ohms.

The insulator to be tested was mounted on a wooden box some four ft. (1.22 m.) from the floor and had a half-inch (12.7-mm.) brass rod tied in the groove by a band of small size copper wires. The pin carrying this insulator was grounded through a wire approximately six ft. (1.8 m.) long. The length of the lead from the transformer terminal to the condenser plate was approximately 50 ft. (15.2 m.)

A series discharge gap was made by approaching a second brass rod mounted on a wooden stand to one end of the ½-in. (1.27-cm.) rod tied to the insulator, the second rod being connected to the sheet iron condenser plate by a wire two or three ft. (60 or 90 cm.) long.

Where a measuring gap was used, as shown by the reports below, this consisted of a needle point gap mounted on hard rubber pedestals located some six ft. (1.8 m.) from the insulator under test. One side of this gap was connected either with or without resistance to the conductor on the insulator under test,

and the other side to the insulator pin or to the ground, as is specified in the particular tests as reported below.

The general method of test was to raise the voltage of the generator feeding the primary until a discharge occurred across the series gap onto the insulator. With the adjustment of generator voltage and transformer ratio used, the result of the breakdown of the gap was in most cases to so reduce the applied voltage that the arc proper would drop out, at least partially, leaving the series gap nearly intact, and thus the return of voltage on the next alternation would be obliged to nearly reproduce the original breakdown voltage on the gap. The effect of this arrangement was to give a continuous succession of static sparks lasting as long as voltage remained on, that is one or two seconds, as distinguished from the holding of an arc over the gap. In the tests of June 24th, however, the opposite effect was secured, that is, a single static spark each time the voltage was raised, followed by a mild arc.

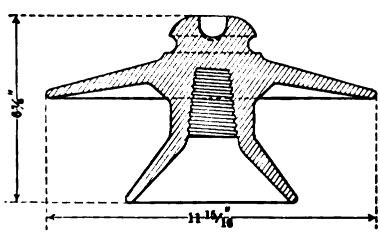


FIG. 1.—ORIGINAL INSULATOR

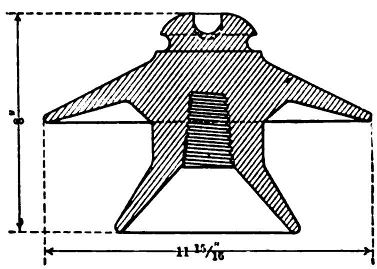


FIG. 2.—PROPOSED 38,000 VOLT INSULATOR

The results of the various tests have been tabulated as follows: and the tests will be considered briefly in groups.

First Group. (*Tests* 1-2) *Normal Flash-Over Test, Dry, in Air, 60 Cycles.*

This group of tests was preliminary and was made in the usual manner the voltage being measured by a spark gap checked approximately by a voltmeter reading on the low-tension winding of the raising transformer.

In no case did an insulator puncture. An insulator of the type shown in Fig. 1, that now in use in the three existing lines, flashed over at 122,000 on the second trial; the insulator of the type shown in Fig. 2 flashed over at 150,000 volts. The insulator of Fig. 2 is a new design that was intended to replace the insulator of Fig. 1 and to better resist lighning stresses. The two insulators are the same except that the later design has a head nearly two

HIGH FREQUENCY TESTS OF LINE INSULATORS

Table of Actual Tests

Test No.	Date 1912	Insulator No.	Description of insulator	Type of test	Series gap	Transformer voltage on spark gap	Result of the test
1	June 24	1	Same as Fig. 1.	60 cycles dry	—	122,000	Flashed over surface, no arc.
2	" "	2	Same as Fig. 2.	" " "	—	150,000	" " "
3	" "	2	" " " 2.	" " wet	—	95,000	" " " , some preliminary sparks.
4	" 25	12	" " " 1.	" " oil	—	205,000	Punctured through head.
5	" "	11	" " " 2.	" " "	—	240,000	Flashed over surface.
6	" "	13	" " " 2.	" " "	—	250,000	Flashed over surface, except for puncture in middle of lower petticoat.
6½	" "	15	" " " 1.	High frequency	25″	342,000	Punctured through head, 14th trial.
7	" 24	3	" " " 2.	High frequency	27″	300,000	Punctured through head after 10–15 trials, hole approx. 1/32 in.-1/64 in. diam.†
8	" "	4	" " " 2.	" "	"	"	Punctured through head after 10 trials as in test 7.
9	" 25	5	" " " 2.	" "	25″	342,000	Punctured through head the second trial.
10	" "	14	Same as Fig. 2, except for ¼″ hole through base of lower petticoat.	" "	"	338,000	Punctured through head 24th trial.
11	" 29	20	Same as Fig. 2, except that 1¼″ is cut off the upper petticoat all around. (Previously flashed over surface on 60 cycles dry at 130,000 volts.)	" "	"	328,000	" " " 6th "
12	" "	23	Same as Fig. 2, except for 4 holes drilled in upper petticoat 2½″ in. from edge.	" "	"	335,000	" " " 28th " about. Examined from time to time before a puncture but showed no incipient injury.
13	" "	28	" " " 2, except top petticoat was cut off at base. (Previously flashed over surface on 60 cycles dry at 90,000 volts.)	" "	"	"	Punctured through head 15th trial.

†This insulator was not hot to the touch after puncture.

HIGH FREQUENCY TESTS OF LINE INSULATORS—Continued

Test No.	Date 1912	Insulator No.	Description of insulator	Type of test	Series gap	Transformer voltage on spark gap	Result of the test
14	June 29	25	Same as Fig. 2, except both petticoats were cut off at base leaving a stump 5 in. high to the tie wire groove and a little over 5" maximum diameter (Previously flashed over surface on 60 cycles dry at 94,000 volts and wet at 33,500 volts.)	High frequency	"	"	No puncture in 150 trials.
15	" "	21	Same as Fig. 1, except that 1¼" was cut off top petticoat. (Previously flashed over surface on 60 cycles at 120,000, dry.)	" "	25"	330,000	Punctured through head, 14th trial.
16	" 25	7	No. 3007 22,000 volt porcelain insulator, see Fig. 6. (Previously flashed over surface on 60 cycles dry at 87,000 volts.	" "	"	235,000	Puncture bottom petticoat 2nd trial; no further punctures in 65 trials.
17	" "	6	No. 3012 35,000 volt porcelain insulator, see Fig. 7. (Previously flashed over surface on 60 cycles dry at 130,000–140,000 volts.	" "	"	"	Punctured lower petticoat, then through middle petticoat, then through head under tie wire, hot at puncture, 20 trials.
18	" "	8	No. 3002, -45,000 volt porcelain insulator, see Fig. 8. (Previously flashed over surface on 60 cycles dry, at 125,000–129,000 volts.	" "	25"	335,000	Punctured through two lower petticoats, 2nd or 3d trial; then punctured through head under tie wire in a few more trials, puncture not very hot.
19	" 29	24	Same as Fig. 2, except that a belt of lead foil was placed around the waist of insulator as in Fig. 3. (Previously flashed over surface on 60 cycles dry at over 138,000 volts.	" "	"	330,000	Punctured through head on 59th trial. This insulator was examined from time to time but no signs of heating or injury were found prior to the failure.
20	" "	26	Same as Fig. 2 except that 4" metal cap was used in head. (Previously flashed over surface on 60 cycles dry at 130,000 volts.)	" "	"	"	Punctured through head, 2nd trial.
21	" "	27	Same as Fig. 1, except that 4" metal cap was used on head. (Previously flashed over surface on 60 cycles dry at 124,000 volts.	" "	"	"	Punctured through head, 17th trial.

HIGH FREQUENCY TESTS OF LINE INSULATORS—Continued

Test No.	Date 1912	Insulator No.	Description of insulator	Type of test	Series gap	Transformer voltage on spark gap	Result of the test
22	June 25	9	Same as Fig. 1, but had been long exposed to weather, surface grey, and checked, especially on lower petticoat.	60 cycles dry	—	105,000	Flashed over surface sparks passing through checks on lower petticoat.
23	" "	10	Same as Fig. 1, but exposed as in test No. 9.	" "	—	120,000	Flashed over surface sparks passing through checks on lower petticoat.
24	" 29	22	Same as Fig. 1, but had been long exposed to weather, surface grey, and checked, especially on lower petticoats; also 1½" cut off upper petticoat all around.	60 cycles dry	—	108,000	Flashed over surface passing through checks in lower petticoat.
25	July 8	31	Same as Fig. 2. (Previously flashed over at 156,000 volts on 60 cycles dry.)	High frequency	22½	315,000	Punctured through head, 9th trial. Pin was warm when examined after test and threads were blackened and split on one side.
26	" "	33	Same as Fig. 2, except that 1½" was cut off the upper petticoat. (Previously flashed over surface on 60 cycles dry at 129,000 volts, wet at at 103,000 volts.	" "	"	302,000	Punctured through head, 113th trial.
27	" "	34	Same as Fig. 2, except that 2½" was cut off the upper petticoat. (Previously flashed over surface on 60 cycles dry at 119,000 volts, wet at 81,000 volts	" "	"	306,000	No puncture in 150 trials.
28	" "	30	Same as Fig. 4, electrose. (Previously flashed over surface on 60 cycles at 115,000 volts dry and 76,000 volts wet.)	" "	21½	310,000	No puncture in 150 trails. Insulator was warm when tests were discontinued.
29	" "	29	Same as Fig. 5, porcelain. (Previously flashed over on 60 cycles at 95,000 volts dry. Insul. 35, same type as 29, flashed over surface on 60 cycles at 118,500 volts dry and 70,000 volts wet.)	" "	"	"	Punctured under tie wire on 3rd trial.
30	" "	32	Same as Fig. 5, porcelain.	" "	"	"	Punctured under tie wire in 2nd trial.

in. (5 cm.) thick in comparison to a head thickness of one in. (2.5 cm.) in the old insulator of Fig. 1. •

Second Group. (*Test* 3) *Normal Flash-Over Test, Wet, in Air,* 60 *Cycles.*

These tests were made with the same electrical apparatus as the first group. Water was thrown on the insulator from three spray nozzles at one side giving a very heavy "scotch mist." The water dripped very rapidly from the petticoats during the tests, but no direct measurement was made of the amount of water sprayed. The water was relatively pure river water.

The insulator of Fig. 2 flashed over at approximately 95,000 volts.

Third Group. (*Tests* 4-6) *Normal Test Under Oil,* 60 *Cycles.*

The insulators were immersed in good "transil" oil, bubbles under the petticoats and in the pinhole being carefully eliminated. The insulator of Fig. 1 punctured through the head at 205,000 volts, and that of Fig. 2, flashed over the surface, once at 240,000 volts and once at 250,000, except that the lower petticoat was punctured at a point intermediate between the edge and the central portion in the latter test.

Fourth Group. (*Tests* 6½-9) *High Frequency Test: apparatus as shown in Fig.* 11.

The insulator of Fig. 2, that is, the new insulator with the 2-in. (5-cm.) thickness of head, punctured from the conductor to the pin. The first two insulators tested failed on the tenth to fifteenth applications of voltage, and the third insulator on the second trial.

This result was most surprising, since insulators of this type had flashed over the surface even *under oil* rather than puncture through the head at 60 cycles. The unusual character of this behavior made a furthur investigation imperative, and the following tests were made.

Fifth Group. (*Tests* 10-15) *High Frequency Tests as in Fig.* 11. (*continued.*)

Insulators of the type of Fig. 2 were altered in various ways and subjected to the same test. As electrose can be sawed and drilled such alterations could be easily made. The results were as follows.

a. With ¼-in. (6.3 mm.) hole drilled at the base of the lower petticoat, the insulator failed by puncture through the head on the twenty-fourth trial.

b. With 1¼-in. (31.7-mm.) turned off the edge of the upper

petticoat, the head failed as before on the sixth trial. This insulator had previously flashed over, as altered, at 60 cycles on 130,000 volts, dry.

c. With four equally spaced $\frac{1}{4}$-in (6.3-mm.) holes drilled through the upper petticoat $2\frac{1}{4}$ in. (5.7 cm.) from the edge, this insulator punctured in the head on the twenty-eighth trial.

d. With the top petticoat entirely cut off, an insulator punctured in the head on the eighteenth trial. This insulator, as altered, had previously arced over on 60 cycles at 90,000 volts, dry.

e. An insulator with both petticoats sawed off as closely as practicable, leaving a stump about 5 in. (12.7 cm.) high to the tie wire groove and a little over 5 in. (12.7 cm.) maximum diameter, showed no failure in over 150 trials. Apparently this insulator

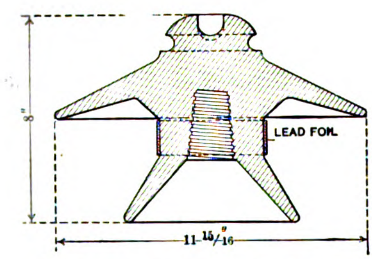


Fig. 3. Electrose Insulator of Fig. 2, with Band of Lead Foil about Waist

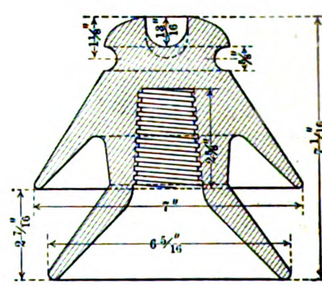


Fig. 4. Type E Insulator—Electrose—22,000 Volts

was capable of standing this application of high frequency of 340,000 volts indefinitely.

f. A similar test was made on an insulator as shown in Fig. 1 with $1\frac{1}{4}$ in. (3.1 cm.) turned off the upper petticoat. This punctured the head as usual on the fourteenth trial. Previously this insulator had flashed over the surface on 60 cycles at 130,000 volts.

These results, which were all on electrose insulators, showed most plainly that the resistance to high frequency stress, in this sort of apparatus at least, bore little relation to its strength against the normal 60-cycle stress. The question naturally arose, were these results peculiar to electrose? Some porcelain insulators were then obtained and high frequency tests made upon them, as follows:

Sixth Group. (*Tests* 16-18) *High Frequency Tests, as Shown in Fig.* 11.

a. A porcelain insulator, No. 3007, recommended for 22,000 volts, showed a puncture in the lower petticoat on the second trial, but suffered no further damage in 65 trials. This insulator had previously flashed over at 87,000 volts, dry, 60 cycles.

b. A porcelain insulator, No. 3012, recommended for 35,000 volts, showed a puncture first on the lower petticoat, then in the middle petticoat and then through the top under the tie wire. This insulator had previously flashed over on 127,000-135,000 volts, dry, 60 cycles.

c. A porcelain insulator, No. 3002, recommended for 45,000 volts, showed a puncture in the two lower petticoats on the first or second trial and a puncture under the tie wire in a few more

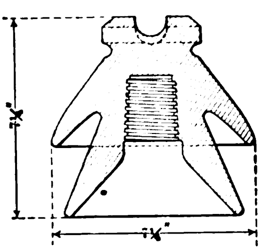


FIG. 5.—TYPE E INSULATOR—PORCELAIN 22,000 VOLTS

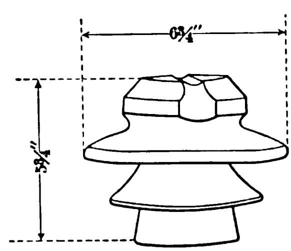


FIG. 6.—PORCELAIN INSULATOR No. 3012

trials. This insulator had previously flashed over at 125,000-129,000 volts on 60 cycles.

From these tests on porcelain insulators it appeared that this feature of failure on high frequency was not peculiar to electrose.

It was surmised that the peculiar effect of high frequency was due to a different distribution of electric stresses produced under this condition, which distribution may be assumed to cause a concentration of potential at certain points. Some tests were therefore devised to verify this assumption.

Seventh Group. (*Tests* 19-21) *High-Frequency Tests, as Shown in Fig.* 11.

a. A new insulator of the type of Fig. 2 was covered with lead foil about the waist as shown in Fig. 3. This foil was entirely disconnected from any metal parts; but, in view of its electrostatic capacity to the pin, it would change the distribution of

potential during the high frequency attack. Its effect would obviously be toward increasing the effective size of the pin top. This insulator punctured through the head on the 59th trial. It had previously flashed over the surface at 138,000 volts on 60 cycles. While this insulator was not proof against the high frequency, it stood up longer than any of the other electrose insulators, even longer than those with reduced petticoats, except the one without any petticoat. This result is very illuminating, as this insulator had all its petticoats intact.

b. A test was made with a new Fig. 2 insulator with a metal cap, about 4 in. (10 cm.) across, on the top of the insulator. The electrical effect of this should be opposite to that of the lead foil of *a* above. This insulator showed a puncture in the head on the second trial. This insulator with cap had previously flashed over at 130,000 volts on 60 cycles, dry.

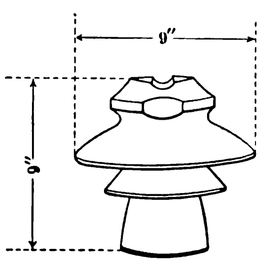


FIG. 7.—PORCELAIN INSULATOR No 3007

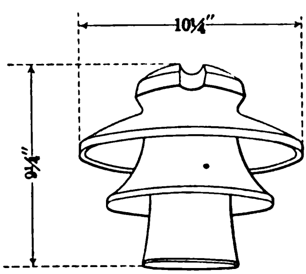


FIG. 8.—PORCELAIN INSULATOR No. 3002

c. The same test as b was made on a Fig. 1 new insulator and the insulator showed a puncture in the top on the seventeenth trial. This insulator with cap had previously flashed over at 124,000 volts on 60 cycles, dry.

These last three results, while few, indicate pretty clearly the cause of the weakness as well as the nature of experiments required to clarify further this matter.

Those electrose insulators of the type of Fig. 1 which had been in service for some years showed a roughening and a bleaching of the surface to a light gray from the effects of exposure to the weather. Some of these old insulators further showed checks on the surface extending to various depths, mostly on the lower petticoat. Tests were made to get the effect of the weathering on the behavior of the insulator.

Eighth Group. (*Tests* 22-24) *Weathering Tests*, 60 *Cycles, Dry.*

a. Two old insulators showed a dry flash-over on 60 cycles on 105,000 and on 120,000 volts, a loss of insulating power of perhaps 10,000 volts, which was undoubtedly due to the arc passing through checks in the lower petticoat. The insulating power of these insulators was thus hardly lessened by the weathering, per se at least as far as it had then progressed.

b. A third weathered insulator with 1¼ in. (3.1 cm.) turned off the edge of the top petticoat flashed over at 108,000 volts, the arc passing through a check on the lower petticoat.

A few days after the completion of those tests, to try still other conditions a further series of tests was made with results as follows:

Ninth Group. (*Tests* 25-27) *High-Frequency Tests.*

These were similar to the previous high-frequency tests but with the insulator mounted on a wooden pin with tin foil wrapped around the pin up to a point ½ in. (12.7 mm.) below the insulator. and grounded.

a. An insulator of the type of Fig. 2 punctured through the head as before on the ninth trial. This design of insulator (which insulator was newly made for this last set of tests) had previously flashed over the surface at 156,000 volts, dry, 60 cycles.

b. An insulator similar to Fig. 2 but with 1½ in. (3.7 cm.) turned off the outer edge of the upper petticoat punctured through the head, but only after 113 trials. This insulator was nearly at the safety point. This insulator previously flashed over at 129,000 volts, dry, at 60 cycles or at 103,000 volts, wet.

c. An insulator similar to Fig. 2 but with 2¼ in. (5.7 cm. turned off the edge of the upper petticoat resisted 150 trials without puncture. This insulator was found to flash over at 119,000 volts, dry, at 60 cycles and at 81,000 volts, wet, under the rain test already described.

Tenth Group. (*Test* 28).

The same high-frequency test on electrose insulators of the type shown in Fig. 4 showed no puncture in 150 trials. This insulator flashed over at 115,000 volts dry on 60 cycles and 76,000 volts, wet.

Eleventh Group. (*Tests* 29-30).

The same high-frequency test on a porcelain insulator of the type shown in Fig. 5 showed a puncture from the tie wire groove to the head on the third trial in the case of one insulator, and on the second trial on another insulator. This type showed a

flash-over at 118,500 volts, dry, at 60 cycles, in one case, and at 95,000 volts in a second case, and a flash-over of 70,000 volts, wet, on the first insulator.

These tests of groups 9 to 11 show that the use of a wooden pin extending only a short distance out from the threaded portion of the insulator, considerably increased its power to resist the high frequency stress.

This result must be due to the prevention of the ground potential from getting up inside the insulator, so to speak. Its effectiveness is, however, somewhat limited by the fact that extremely severe potential shocks, such as were here produced, tend to cause a discharge over the surface of the pin into the insulator pin recess. If this pin were cemented air tight into the insulator the result would presumably be to increase the power of the insulator to stand high-frequency tests.

Certain other tests which are of interest were made to measure the actual voltages reached on the insulator during discharge. Measurements were made by noting the voltages that would jump the spark gap marked " measuring gap " in Fig. 11 under certain discharge conditions.

a. During the high frequency test on a Fig. 2 insulator, (test 8), sparks were observed in the measuring gap when it was set at 10 in. (25.4 cm.), 104,000 volts, (needle points) but no sparks occurred when it was at 11 in. (27.9 cm.) 112,000 volts. There were 125,000 ohms (seven composition sticks) in the shunt measuring gap circuit when these readings were taken. This indicates a maximum voltage during the high frequency attack of slightly over 100,000 volts. This result, which should be compared with the 150,000 (15-in. or 38-cm. gap) necessary to make the insulator flash over at 60 cycles, shows that there must have been a great local concentration of voltage on portions of the insulator at the high frequency. This is an important point in connection with surges produced by internal causes. If a 100,000-volt static voltage will pass over or through an insulator which flashes over at normal frequency only on 150,000 volts, this fact should be recognized.

b. With the same arrangement as in above, except that the insulator was short circuited by a No. 18 copper wire, drawn tight between pin and tie wire groove, a voltage sufficient to jump a needle gap corresponding to 15,000 volts was noted, and no spark occurred over the gap when set for 20,000 volts. No resistance was used in the measuring gap circuit in this test.

c. With the conditions of test b above, except that five separate No. 18 wires were used to short circuit the insulator at points equally spaced around its circumference, a spark gap of ½ in., (12.7 mm.), corresponding to 10,000 volts, was jumped, but no spark was found with the spark gap set at a value to indicate 15,000 volts. No resistance was used in the measuring gap circuit in these tests.

Discussion of Tests

The obvious meaning of these tests is of great import. Unless there is some reason for believing that the tests are only of limited application or are rendered misleading by some unobserved condition, they mean that many of the line insulators now in service may be expected to break down by puncturing under the attack of lightning rather than by discharge over the surface, as is recognized as the desired characteristic. And this in spite of the fact that these insulators may have been thoroughly tested on normal frequencies in the usual way and may have then always flashed over the petticoats as intended. The fact shown in these tests, that an insulator which did not puncture at 250,000 volts on 60 cycles (under oil), punctured after a comparatively few shocks of high frequency discharge, and without apparently opposing a resistance of much over 100,000 volts (10-in. (25.4-cm.) spark gap), shows how little can be determined from the 60-cycle tests, as to the lightning resisting capacity of an insulator.

While none of the tests were on trains of suspension insulators, the question immediately arises whether the same effects, that is, local concentration of voltage with high frequency shocks, will not cause these insulator trains to puncture relatively easily from lightning even when withstanding satisfactorily the most severe tests of the usual sort. Such failure is very likely to be expected. High-frequency tests on such insulator trains should be made by all means, and without delay.

The conclusion also is forced upon us, that if high-tension line insulators are to be adapted to resist lightning to the best advantage, the design of many of them should be radically changed. Such a design study will require much patient investigation. In view of the importance of these conclusions, a critical examination of our tests was made for the purpose of discovering any improper methods or errors that might account for the great weakness of the insulators under high-frequency shocks; nothing, however, so far has been found to explain more than a very small portion of the very great discrepancy between the results of the two types of tests.

Considering the material of the insulators, most of which were electrose, we should say that insulators made in at least four different lots, distributed over a period of several years, showed the same consistent behavior. Further than this, four different types of porcelain insulators were tested and all showed this effect, although the lower-voltage insulators showed it in a less degree than the higher-tension insulators. In the case of the insulators of Fig. 4 and Fig. 5 the shape of the insulator was the same and only the material was different. Of these, the electrose insulators behaved best on the high frequency test.

One very significant point is that no insulator failed on high frequency on the very first shock. In fact the strain of repeated shocks seemed to be far more severe than that of a few. Probably there is a progressive hammering out of a path through the solid material of the insulator. It will be immediately suggested, that this effect may be due to a progressive heating of the material by conduction or dielectric hysteresis, but we are inclined to doubt this. Investigations were made by exploring with the finger during the tests and, while after a puncture, which would of course be followed by some arcing, there was often a very noticeable rise of temperature at the puncture, exploration before an actual puncture but after the occurrence of many shocks showed no detectable preliminary heating. Furthermore, there seemed to be no difference in the behavior of electrose and porcelain. This matter of dielectric loss and heating is of course one of the matters that should be carefully followed up in future tests along these lines. If the effect of the greatly increased severity of many shocks was due to the heating effect, it is not likely that the cutting off of the petticoats would be so effective in increasing the resisting power.

It has been suggested by some that porcelain deteriorates in quality with time or exposure to the weather. This hypothesis is supposed to explain the fact that insulators which stand up under tests and during the initial months of actual service then seem to fail far more readily at a later time. It is suggested by the behavior of the insulators of our tests that there was progressive deterioration under the intense stresses of these experiments (or under the attack of lightning in actual service), which while due to electrical forces are of a physical nature. This would be somewhat analogous to the well-known mechanical disintegration of the surface of glass under repeated surface sparking. In this view, the repeated attacks of these tests represent the antici-

pated effect of several seasons of lightning storms; to put it another way, the tests serve as a measure of the service durability of an insulator, as far as lightning and static are concerned.

These tests were made in a large transformer testing pit, but it is not likely that the presence of the grounded sides of the pit several feet away could have had any material effect on the results.

While the 60-cycle tests and the high-frequency tests were made on different testing outfits, there can be no great error here. The 60-cycle test were made on a 300,000-volt transformer, regularly and frequently used for such testing and the ratio and spark gap methods of measuring the high-tension voltages were about five per cent. apart, the voltage actually reported being the spark gap voltage as recommended by the Standardization Rules of the A. I. E. E. The character of the high-frequency tests was of course determined by the series spark gap and the constants of the plate condenser discharge gap. The high tension condenser had approximately 72 sq. ft. (6.7 sq. m.) surface and a dielectric thickness of 42 in. (1.06 m.) of air. The discharge path of the condenser was roughly rectangular in form, 5 by 7 ft. (1.5 by 2.1 m.), including the series gap and the insulator itself.

An estimate of the natural oscillation frequency of this discharge circuit would be roughly—that it was of the order of 1,000,000 cycles per second or higer. The noise of the discharge during the tests was very loud and some of the observers used cotton in their ears to avoid the disagreeable physiological effect. While the highest voltage of the high frequency tests was in the neighborhood of 300,000-350,000 volts, and the quantity of the discharge great for laboratory tests, it was of course far short of lightning conditions in both particulars. The frequency, however, may have been comparable with that of lightning.

The probability of the trustworthiness of these tests is greatly increased by the behavior of insulators in actual service, where punctures of a surprising character have occurred at the time of lightning or other disturbance of a static nature. We are informed that trains of suspension insulators and also pin type high tension insulators which are carefully designed and shown by test at normal frequency to flash over before they puncture, still do in practice actually puncture under lightning strains. It is a fact, however, that many of these insulators at other times

do actually flash over in actual service instead of puncturing under static stress, showing that either all insulators or all stress conditions are not the same. This matter cannot be finally cleared up without much experiment and research.

Cause of the Peculiar High Frequency Effects. Of the most interest and importance is of course the explanation of the cause of the great observed discrepancy between the effect of high-frequency tests and commercial frequency tests. It is too early to speak with certainty, but there is little doubt that the principal cause is the concentration of potential with high frequency upon some local part of the insulating material with the result of the breaking down of this portion and the throwing of the potential on some other part which is then also broken down. This general phenomenon is well-known in related situations; for example, in the behavior of trains of small air gaps in high-tension lightning arresters.

If a resistance and a capacity are connected in series and so adjusted that a given voltage at 60 cycles is evenly divided between the two, and the same voltage at a much higher frequency is impressed on the two, it will be found that the resistance then receives nearly all the voltage and the condenser practically none at all. The same would be true to an even greater extent were an inductance substituted for the resistance. An adjustment may easily be arranged in which at 60 cycles the condenser will take all the voltage and at the high-frequency the resistance would take all the voltage. In applying this principle to insulator service, it must be remembered that the change in frequency between 60 cycles and the frequency of lightning is enormous, the ratio being somewhere of the order of 1 to 1,000 or 10,000, which gives range enough to permit even a small tendency of 60 cycles to be transformed into a dominating effect on the lightning frequency.

Consider Fig. 9; the small condensers indicate the capacity of various parts of the insulator surface to which the potential of these parts is due and the small resistances indicate the insulation resistance of the corresponding dielectric material of the insulator. At 60 cycles, the charging current for the several small condensers, 1, 2, 3, can easily flow through the several resistances, 4, 6, etc., without the impressing of any very great potential upon these resistances. With a high frequency, however, as just explained, the full potentiai may be impressed on the resistance for the moment, or, in fact, for as long as the high

frequency lasts. Thus the resistance 4 which charges the surface capacity 1, which is a relatively large capacity, may on high frequency have to support nearly the full voltage of the attack which it is evidently not adapted to do. But there is also a leakage of current toward the tie wire and conductor which will flow over part of the path of the resistance 4. Since the surface of the pin is much smaller than that of the surface of the insulator, the concentration of leakage current will be greatest at the former and the first break or failure of the insulating material will occur at this point. When this occurs the voltage on the conductor and tie wire will tend to cause a puncture through this weakened

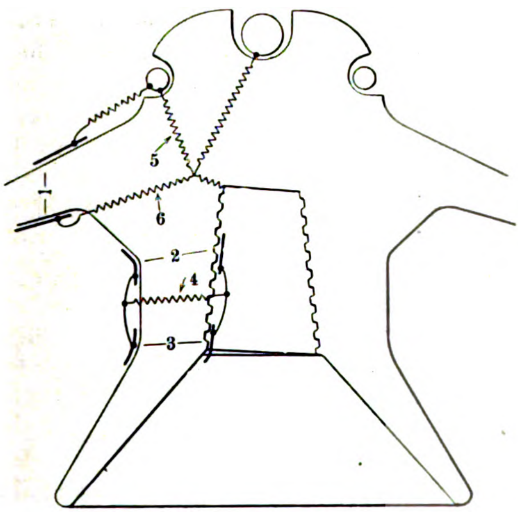


FIG. 9. ILLUSTRATION OF ELECTROSTATIC CAPACITY OF SURFACE AND INSULATION RESISTANCE OF THE VARIOUS PARTS OF THE INSULATOR

material and thus make a puncture from the conductor to the edge of the top of the pin. This is what was actually observed. This explanation is, however, given rather as illustrative of the general tendency of the distribution of force, than as a correct picturing of the action in detail, for this would be very hard to establish directly.

According to this view the effect of the lead foil of test 24, which showed a great strengthening of the insulator's resistance was to permit the charging of the small condenser 1 through the foil in virtue of the capacity of the foil to the pin and in virtue of the fact that a free charge of opposite sign could be repelled

to the lower end of the foil. So far as it goes then, the foil test tends to confirm the distribution of potential assumed above in connection with the discussion of Fig. 9.

Looking at this matter from another point of view, which, however, in substance is much the same, it is evident that the conductor and the wire on the top of the insulator form the electric equivalent of a hemisphere, and that the pin top is in effect a small discharge point near the center of the hemisphere. This form is one in which the distribution of electric field is most uneven, for its intensity is greatly concentrated at the center on the pin top, and much less intensity exists at the conductor and the tie wire. This condition is somewhat similar to that of a cable with a lead sheath and a relatively small conductor inside. It is found in such a cable that if the diameter of the conductor is smaller than that of the sheath by more than a certain ratio that little gain in insulation strength is made by increasing the thickness of the insulation and the diameter of the sheath. This is because the potential becomes more and more concentrated at the center and this part fails first, so that the added insulation is later broken down by itself. However, in the case of the tests here described the effect of resistance and capacity in series, assumed in the discussion of Fig. 9, is probably present, for this sort of concentration comes from high frequency only, while that described in connection with cables occurs at all frequencies. It is significant that the use of a metal cap only weakens the insulators in the tests (see tests 26 and 27) as would be expected from these explanations.

High Frequency Tests. It will naturally follow from the conditions indicated by these tests, assuming that they are confirmed by later investigators, that it will be desirable to modify our methods of testing insulators for practical work by adding tests of their behavior on high frequency. Such tests presumably need not be made on all the individuals entering into a plant, but on each type, to show that the design is satisfactory. Such tests will be difficult to make, in the first place, because very high voltage and large capacity are necessary for making the tests, and second, because these tests are dangerous to the testing apparatus used and because so far there is no knowledge as to what limits of frequency, voltage, electrostatic capacity or number of repetitions of attack are necessary to give a proper measure of the conditions of actual service. These service conditions will undoubtedly vary greatly in different localities. It

can be suggested here only that further study of these phenomena be made as speedily and as exhaustively as practicable.

Design of Insulators.—In the matter of new designs of insulators to resist high frequency discharges, much research should be done, but there are some guiding principles already clear. First, the more widely the live conducting parts of an insulator are separated from the pin, the less will be the stress. Second, the more nearly uniform the electrostatic field between these elements is, the better the condition. Third, wide and thin petticoats add very little strength to the high-tension insulator, for the electrostatic capacity of the surfaces of the outer parts is very great with regard to capacity of the parts nearer to the pin. It is very likely that the capacity of the wide petticoat of the insulator of Fig. 1 or Fig. 2 plays little part in its behavior on high frequency, since the potential stresses may be transmitted through the petticoat by virtue of the capacity of the lower surface in relation to that of the upper surface. This would account to some extent for the behavior observed. It is significant that the type which stood best, that of Figs. 4 and 5, had short and thick petticoats placed low down with regard to the pin top. The heavy ball of insulating material at and around the head of the pin is very likely the chief reliance of the insulator on high frequency.

It will be noted that the design of the present suspension insulator has some points of disadvantage from the point of view of static stresses, if these tests are to be relied upon.

Effect of High Frequency on Lead Covered Cables. From the analysis of the necessary effects of applying very high frequency to structures having electrostatic capacity and high resistance in series, it is suggested that these high frequency strains may have a very trying effect on lead covered cables. Here the layers of the insulating material next to the conductor may receive a far greater concentration of potential from high-frequency stresses than from 60-cycle stresses, for example; in which case static disturbances may break them down at a lower voltage than under normal conditions. As the great susceptibility of cables to static disturbances has been frequently observed in actual service, a series of cable tests after the type of those here reported would be of the greatest interest.

The great difficulty in such tests would be to get some reliable measure of the equivalence of voltages on high-frequency and low-frequency.

Fig. 10, shows the insulator and pin finally adopted by the power company. The pin consists of an iron base for attachment to crossarm, and metal sleeve with conical bore to receive a wooden pin, which is secured in place by the pressure produced in screwing the sleeve and base together. The wooden pin is impregnated with bakelite to prevent absorption of moisture.

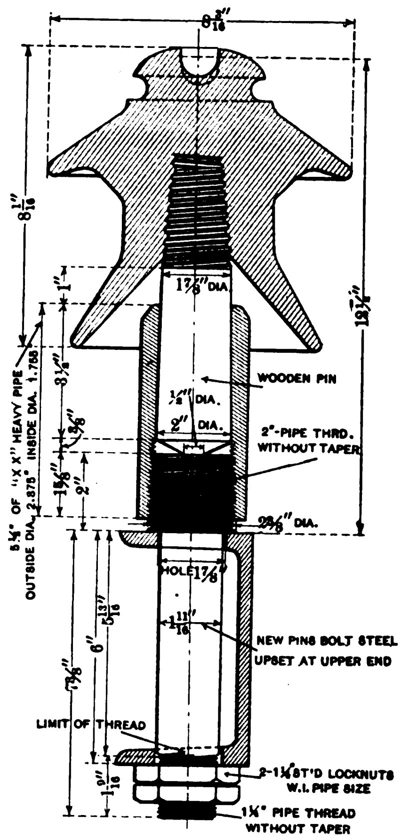


Fig. 10. Section of Insulator Finally Adopted

No attempt was made to cement the pin in the insulator, but this can readily be done if experience indicates that it is desirable. The insulator thus mounted on the combination wood and iron pin will withstand a breakdown test at 60 cycles between a conductor in the tie-wire groove and the iron pin, of 120,000 volts, dry, and 85,000 volts, wet. It is highly probable that if

time had permitted a better design of insulator could have been developed, but the construction of a new line was under way and the order for insulators had to be placed. The design selected was that which our tests had shown to be best able to resist the high-frequency discharges which we were able to obtain in the laboratory. It remains to be shown by experience whether these insulators will resist puncture from all lightning discharges to which they will doubtless be subjected.

Suggestions for Investigations. We would make the following suggestions, the application of which will be clear from what has been said above.

a. Those who wish to get an idea of the behavior of their

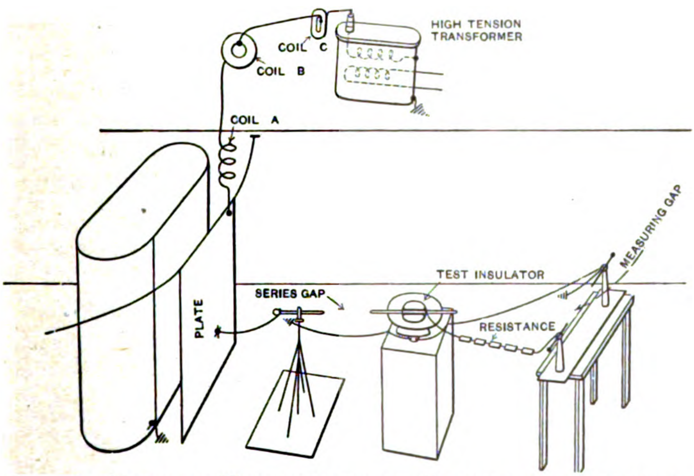


Fig. 11. View of High-frequency Testing Arrangements

insulators on high frequency without waiting until a generally accepted test is developed, should utilize the arrangement of apparatus of the tests here described which has been found very satisfactory and as practicable as any is likely to be.

b. Those who wish to do research work on this line of investigation, should study:

1. The effect of frequency itself on some standard type of test insulator, by varying the constants of the high frequency discharge circuit.

2. The effect of high frequency on trains of suspension insulators.

3. The effect of the distribution and size of petticoats and

the control of the potentials of various parts of the surface of the insulators, for example, by the use of conductors distributed on the surface, as in the above lead foil test, and especially the location of the petticoats with regard to the top of the pin and the thickness of the base of the petticoats.

4. The effect of a wooden or other insulating pin. Especially the effect of cementing the pin air tight in the socket. With a wooden-topped pin and an insulator so mounted and shaped that any discharge would take place to the *crossarm* and not to the pin, many of the electrical advantages of a metal pin would be obtained, with probably greatly increased possibilities of resisting puncture by lightning.

5. The high-frequency test as a test, to determine the effect on the behavior of any insulator, of variations of *test frequency*, of the amount of the *excess series gap voltage* over and above the *flash-over voltage* of the insulator, of the amount of *static capacity* connected with the high-frequency discharge circuit, of the *length* and character of the *discharge* path, and the effect of the method of securing the actual conductor and tie wire during the test.

In conclusion we would state these tests are reported to the Institute for their great interest and suggestiveness, but with the full consciousness that they are far from complete from the broad point of view of the effect of high-frequency voltages on high-tension insulators.

Discussion on "The Use of Reactance in Transformers," (Moody) and "The Effect of Temperature upon the Hysteresis Loss in Sheet Steel." (MacLaren) New York, October 11, 1912. (See Proceedings for October, 1912.)

(Subject to final revision for the Transactions.)

Philip Torchio: Mr. Moody states that outside reactances are equally effective and in practice superior to reactance within the transformer. Different attempts have been made to obtain a design of such reactances that would give the best results as to economy and safety, and also meet with the operation and installation requirements in stations. Mr. Moody gives in Figs. 4 and 5 views of a drum-wound reactance of large capacity. I desire to describe a design of reactance which has certain important features that might be of interest to the Institute members.

These characteristic features are:

1. The adoption of the pancake winding instead of the drum winding.
2. The adoption of an enclosed case and supports of fireproof and insulating materials throughout.

By means of these two features several marked advantages are obtained.

The pancake-wound coil can be designed more efficiently, and for the same floor space, of considerably less height than an equivalent drum-wound reactance. This is due to the fact that windings and layers can be placed closer together for the same potential gradient between layers. It is also a well known fact that for the same outside diameter, the shorter the coil the greater the reactance for a given number of turns. These two facts combined make the drum-wound coil, for approximately the same per cent reactance and the same floor space, about twice as high as an equivalent pancake wound coil. This causes a greater leakage of flux which creates a greater tendency to eddy current losses and requires a greater length of conductor and consequently more heating and losses.

The adoption of a coil with porcelain supports and self-enclosed in a case made up of fireproof and insulating materials gives a greater factor of safety and other obvious practical advantages to the user.

These self-enclosed, self-cooled reactances are built of horizontally wound spirals supported and insulated by porcelain arms with suitable recesses for the windings; the arms are assembled radially as vertical walls between a center core of alberene stone and outer enclosing wall built up of special porcelain segments. These cellular compartments as formed allow natural ventilation for the coil. The whole is supported at the two ends by heavy concrete headers, securely fastened to the wall by a series of brass bolts passing through the heads and the special porcelain segments from top to bottom. Ventilating holes correspond with each vertical cellular compartment of the coils.

The heating is very small and considerably less than the heating of the generator itself, which was accomplished by a special treatment and design of the stranded conductors. These conductors are also insulated throughout to prevent short circuits from foreign objects falling or being drawn into the coil. Each coil is tested to ground at five times the working potential.

Figs. 1 and 2 show the separate pieces and an assembly section of the different insulating materials for encasing the coil. Fig. 3 shows a top view of a coil under construction, showing the way the winding is laid in the porcelain arms. The brass rods are insulated by mica tubes throughout their length. Fig. 4 is a photograph of a set of three coils in service. The coils are resting upon eight small concrete pillars and insulators to allow air space for natural ventilation. The overall dimensions are 59 in. (1.5 m.) in diameter and 55 in. (1.4 m.) in height. The winding inside the case is 45 in. (1.14 m.) diameter and the height over copper is 30 in. (0.76 m.)

The same design is used for different sizes of generators and different frequencies, the only changes required being in the number, size and shape of slots in the radial arms, and the number of layers assembled in one coil.

The attached table gives the constants of a set of reactances operating on three 20,000-kw. 6600-volt, 25-cycle generators installed by the New York Edison Company. The table also gives the results for the same coil at 62½ cycles; the latter to be used for a sectionalizing bus reactance in a large station.

	62½ Cycles		25 Cycles	
Number of turns	34.		34.	
Reactance in Ohms	0.227		0.0914	
Reactance in per cent	10.4 per cent		4.2 per cent	
Equivalent resistance	0.00254		0.00204	
Ohmic resistance	0.00197		0.00195	
Calculated a-c. resistance	0.00215		0.00198	
Current	1750.	amps.	1750.	amps.
I^2R losses	6.57	kw. per coil	6.05	kw. per coil
Foucault losses	1.17	kw. per coil	0.186	kw. per coil
Total losses	7.81	kw. per coil	6.236	kw. per coil
Temperature rise full load 3 hours	43.7 deg. cent.		33. deg. cent.	

L. W. Chubb (by letter): Professor MacLaren's paper is certainly a valuable addition to the general knowledge of the influence of heat upon the magnetic properties of sheet steel. Such papers on magnetic phenomena not only add the data given but are unusually fruitful because of the suggestions for future work.

The paper by the same author last year was of great value because it showed that the law of variation between loss and magnetic induction was practically the same at all temperatures. The suggestion made that rate of heating probably affected the change in loss has been covered briefly by the paper under discussion but the relation between loss and temperature, as a function of rate of temperature change is too involved, and depends upon too many variables to be disclosed by a few tests

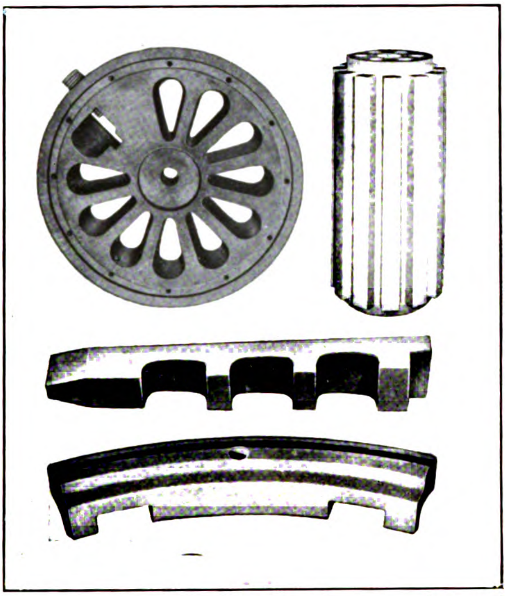


FIG. 1 [TORCHIO]

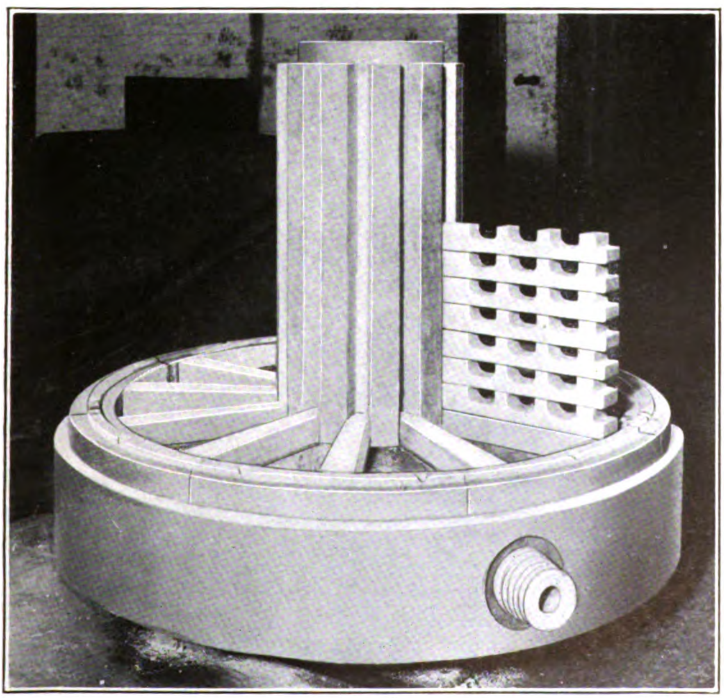
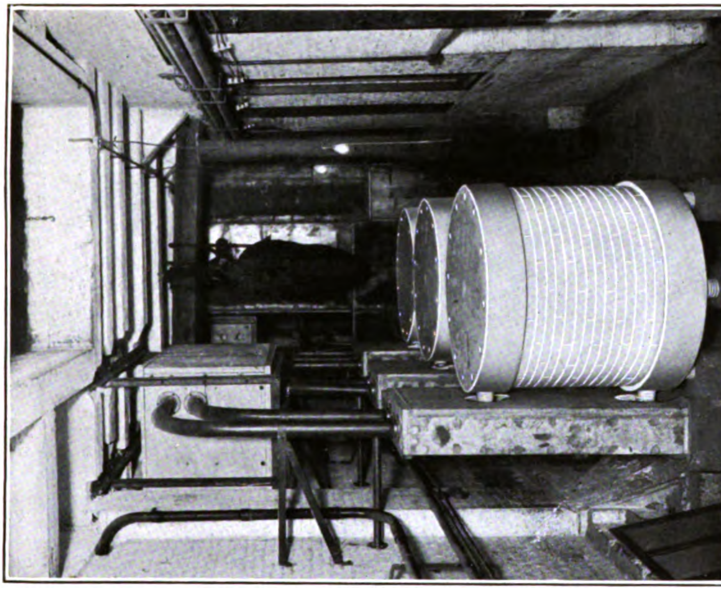
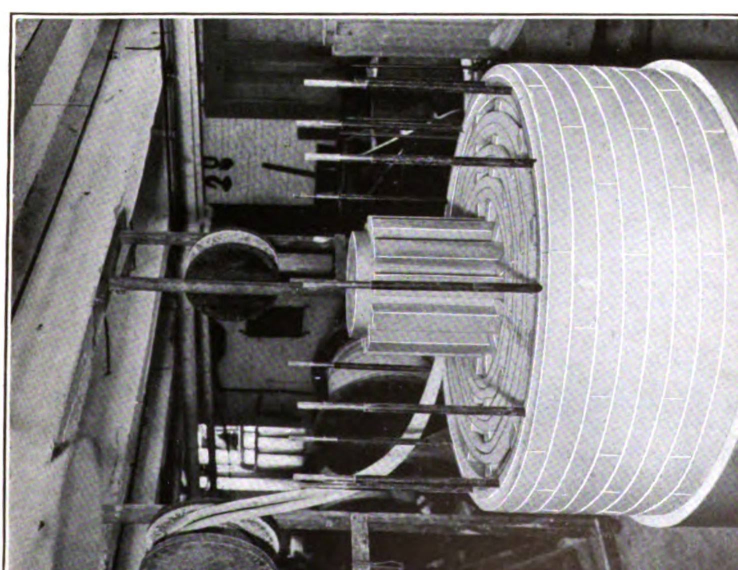


FIG. 2 [TORCHIO]



[TORCHIO]

FIG. 4



[TORCHIO]

FIG. 3

on a few samples of steel. The general trend of the curve is shown by the tests and some very interesting points have been brought out because the author not only gives results of the hysteresis or loop area, but has given the actual loops and thereby shown the relation between permeability and temperature. The changes in shape of the hysteresis loops and the odd shapes at the magnetic-point are very interesting.

In the work with which I have been connected, a limited number of experiments were made to find the effect of rate of change of temperature upon the loss at different temperatures, and to determine if any great change in the cycle of temperature would have its effect upon the losses. The results were too variable to be of value and it was necessary to study only the effect of the heat cycle upon the losses at atmospheric temperatures before and after heating. This of course is the familiar problem of annealing. Within certain limits of temperatures the rate of change in temperature has the opposite effect upon the instantaneous value of the loss. A pause in temperature at some values will have no effect on the loss, at others it will raise such loss, and at others it will lower the loss. Tests show that although such holding of temperature may not change the loss at the *given* temperature it will change the loss at *other* temperatures. Also at certain points a pause in temperature that will appreciably age the steel at the given point while held constant will cause a lowering of the intrinsic loss at other temperatures, other parts of the temperature cycle being the same.

The study of temperature cycles on the final losses at temperatures at which laminated cores operate is of the greatest importance and it is this study which will probably result in the greatest improvements in sheet steel in the near future.

The arrangement of samples which was used under test may be of interest. The first tests were made upon small shell-type punchings built into coils of asbestos-covered wire. The results were not accurate but were relative. The later tests were made by placing a ring sample around the leg of a large transformer core and heating it as a short-circuited secondary. The sample was taped with several layers of asbestos tape and wound with a primary and secondary of asbestos-covered wire. The temperature of the ring sample was very uniform and could easily be controlled by variation of flux in the transformer core. The sample was so well heat-insulated that the windings were relatively cool and gave no oxidation trouble. The wattmeter method was used in both cases.

Professor MacLaren's loops are certainly a recommendation for the method of " slow reversals " and the points plotted seem to show great accuracy. I believe that the results are worthy of careful analysis and that it is to be regretted that all of the loops were not reproduced in the paper so that the progressive changes in magnetizing components could be followed.

C. A. Adams: Mr. Moody's very interesting and instructive paper illustrates a not uncommon experience in the development

of electrical plant and apparatus; namely, that when a certain size is reached, qualities which for smaller sizes were considered as objectionable and the reduction of which was considered of sufficient moment to warrant the partial sacrifice of other desirable qualities, pass through a critical stage and we suddenly find ourselves straining other points in design in order to increase this erstwhile objectionable feature.

The reason for this is usually the appearance of a new limitation such as that of mechanical strength in the present instance. But why should this limitation appear in large rather than in small sizes, since the short circuit current of a transformer in terms of its full load current, does not increase considerably with size beyond a comparatively low limit. Here is an interesting illustration of the operation of one of those laws connecting the quality of a physical organism or piece of apparatus with its linear dimensions. A large piece of stone will fall through the air without feeling appreciably the atmospheric resistance, but a sufficiently small piece of the same stone will float in the same air as a dust particle, because the weight decreases as the cube and the friction surface as the square of a linear dimension. A flea can jump hundreds of times his own length, but an elephant can't jump at all, because weight increases as the cube and muscle cross-section only as the square of a linear dimension. Numerous other illustrations of the most fundamental nature could be provided to explain other limitations and critical values.

The connection between the relative mechanical strength of a transformer coil under short-circuit and the size of the transformer, is not quite so obvious; but as it may be of interest to many here, I will attempt to explain it briefly.

Imagine every linear dimension of a transformer to be increased in a certain ratio, the current density in the copper and flux density in the core remaining the same; the cross section of the magnetic leakage path will increase as the square, its length as the first power, and therefore its permanence as the first power of the linear increase. The current linked with this path will increase as the square and therefore the flux as the cube. The useful flux will increase as the square; therefore the per cent leakage flux and the per cent reactance will increase as the first power. To avoid this increase a larger number of interlacings between the primary and secondary coils is ordinarily employed in the larger sizes.

Assume first that the number of interlacings is not changed. The leakage flux density will increase as the first power, the current as the square, the length of current path as the first power, and the mechanical reaction of the two on each other as the fourth power of the linear dimension. Moreover the length of the coil extension and thus the lever arm of this force will increase as the first power, and the moment of the force about the coil support as the fifth power.

If the coil section were solid in each case, the moment of inertia of its cross-section and its stiffness would increase as the fourth power, and therefore its relative stiffness inversely as the first power. But if the coil is built up of wire, the linear dimension of whose cross-section does not increase as much as the linear dimension of the transformer, the stiffness will increase by less than the fourth power, and the relative strength be still less than inversely as the first power.

Assume now that for purposes of ventilation, the coils are kept at the same thickness, and that in order to keep down the reactance, the interlacings between the primary and secondary coils increases as the linear dimension. This approaches approximately to common practise. Then the leakage flux density will be the same, the current in a single coil will increase as the first power of the linear increase, the length of the current path as the first power, and the lever arm as the first power. Thus the bending moment will increase as the cube. But as the stiffness will increase as the first power only, the relative strength will be inversely as the square of the linear increase.

If, in order to increase the reactance, n of these same primary coils be grouped together in place of being interlaced with secondary coils, but be separated from each other for ventilation purposes, the density of the leakage flux adjacent to the outside coil will be n times as great and thus the relative strength $\frac{1}{n}$ times as great as for the completely interlaced arrangement of the same coils and the same short circuit current; but the latter will be much less owing to the n^2 times as much reactance.

With the common method of construction there is thus a limit of size beyond which extraordinary methods of coil support, or some form of current limiting reactance must be employed.

David B. Rushmore: The very interesting subject brought up by Mr. Moody, is, I think, indicative of one of the critical changes that are taking place in electrical development. In much of our historical work we alter and improve by very slow methods up to a certain point, and then we are apt to make very radical changes. As we all know, in the small apparatus which we have been using there was sufficient inherent reactance to furnish the desirable characteristics; but the very large power stations of the present day have brought into play such large concentrations of energy that the destructive effects are no longer controlled by the natural characteristics of the apparatus, and we have had to artificially introduce into such machines and into such system qualities which previously we bent all our efforts towards keeping out.

When we think of what reactance is and why we introduce it, in general terms, or why we do not want it and why we have got to have it, the thought comes to us that reactance is comparable to inertia. In other words, it introduces inertia into electrical

movement. It introduces into inertia a capacity for the storage of energy and also a capacity for the reflection of wave motion. Reactance is used in some places for one reason, and in other places for still another reason. The tremendous mechanical force brought into play by the short-circuit current, and especially the instantaneous short circuit currents of apparatus and installation, is so great that it has to be lowered in some artificial way.

In introducing the reactance into machines, speaking now especially of the subject of alternators, we are confronted with the fact that in all designing a compromise has got to be made. The desirable qualities of reaction when put into a machine introduce certain undesirable features of bad regulation, and also the fact that practically all voltage fluctuations that we get are across reactance. I shall always feel indebted to Prof. Rosa for an article which he wrote years ago, which expounded to my youthful mind how we could neutralize capacity in reactance and what actually happened.

Introducing reactance into transformers also introduces the possibility of a very serious rise of potential, especially with high frequency currents. These are naturally guarded against in other ways, but still this is the reason why in generators, for example, it is one of a number of points which make it desirable to put the reactance outside of the machine rather than to introduce it all into the armature, and in that way sacrificing other qualities of manufacture, repair, and conditions of operation. Introducing it into the transformer, as Mr. Moody has explained, does not protect the transformer itself; and the reactance is now finding a considerably wider application in bus bars, together with its introduction into machines.

Reactance is also used—and very likely in the future will be used to a much larger extent still—for another purpose which has been mentioned, namely, that of protection against high frequency and high voltage disturbances. A person naturally wonders why iron is not used with current limiting reactances. Naturally one would think that it would be very much more efficient and thus reduce the size of the coils. The densities, however, that are employed, are so great that iron is of no benefit. It is quite startling when you think of magnetizing the surrounding air.

While it is rather difficult to add much that is new to the discussion without entering the field of speculation, I think it can well be said that the use of reactance both for current limiting devices and self protecting devices is undoubtedly to increase much in the future. It is one of the refinements of the art which is going to be studied; it is a new refinement of analysis, and I think the work of the engineer in the future is going to be very largely concerned with the proper use and application of such reactances.

W. M. McConahey (by letter): Mr. Moody's paper is very timely as it deals with a phase of transformer design that is of

great importance in large power transformers and, generally speaking, is but imperfectly understood.

Low reactance has been considered desirable because of the good regulation it gives on inductive load. With large power transformers this is unimportant. What is of great importance, however, is that the reactance be of such a value that the mechanical stresses on short circuit will not be such as to make it difficult to prevent damage to the windings. There is a widespread impression that merely changing the design so as to increase the reactance will reduce the short circuit stresses. This is true only within limits and in some cases an increase in the reactance will actually increase the stresses.

Formula (I) of Mr. Moody's paper shows the elements that enter in to determine the reactance of a transformer and formula (III) shows those that enter in to determine the short circuit stresses, the current in the latter case being that which flows on short circuit and which is determined by the impedance of the transformer. An inspection of these formulas shows that practically the same elements enter into both, thus indicating the close relation between reactance and short circuit stresses.

In large transformers of 50 or 60 cycles, particularly if they are for high voltage, it is not difficult to so proportion the design that they will stand up successfully under the most severe short circuit conditions. For 25 cycles the problem is much more difficult and if the voltage is comparatively low, the difficulties are still further increased. However, by careful designing and the use of substantial mechanical construction, satisfactory low-frequency transformers can be built in moderate sizes without resorting to any special form of construction or the use of outside protective reactances, but in very large sizes, one of these special methods of protecting the windings against excessive mechanical stress may have to be employed.

As stated by Mr. Moody, in a 2:1 auto-transformer, the effect of the reactance is reduced by one-half. In a recent case involving the design of some 2:1 auto-transformers for railway service, the short circuit stresses were found to be so heavy that it was deemed advisable to reduce them by a mechanical separation of the primary and secondary parts of the winding. This of course increased the cost of the transformer but it is cheaper than supplying outside reactances which in this case would not have been acceptable.

Exceedingly low reactance, giving very close regulation on inductive load, not only makes it difficult to brace the coils securely but it also increases the cost.

The scheme of placing strips of laminated iron between the primary and secondary coils in order to increase the leakage flux and thus secure high reactance in transformers, particularly for operating rotary converters, is one that the writer tried out as far back as 1899 and has used many times since with entire success. I cannot quite agree with Mr. Moody that by this

scheme " the copper will be entirely shielded from eddy currents" because there will be leakage flux inside the coils themselves as well as in the space occupied by the laminated iron, and there will also be a fringing flux cutting into the coils around the air gaps in the iron. These fluxes will have an appreciable effect in producing eddy currents in the copper. With this scheme however high reactance can be secured with much less eddy current loss than with the ordinary type of design because a comparatively few number of turns can be used in the windings, thus securing a low magnetomotive force and consequently a weak leakage field through the windings.

Charles F. Scott: Mr. Moody's paper presents the subject in a simple, clear and analytical way, and the author has made himself understood without very many differential equations.

In placing the iron shunts between the coils, he says that they can be used to modify the regulation of the transformer up to say 50 per cent overload, but that this is not a remedy for excessive current on short circuit.

In this connection I have been looking at Fig. 3, showing the cross-section of the transformer, and have been trying to imagine what the probable effect would be with a current on short circuit. As I understand the situation it is that as current is increased above normal the reactance continues to be very high until the saturation of the shunt prevents its becoming proportionately greater, so that the transformer on short circuit would probably give say three-quarters of the current that it would without the shunts. In order to make the shunts fully effective under conditions of short circuit it would be necessary to make them pretty large. If that were done in Fig. 3, the shunts would present a total area equal to a large fraction of the area of the main core of the transformer, which would introduce a number of difficulties and complications.

Prof. MacLaren's Fig. 1, in which he shows a ring with a primary and a secondary coil around it, leads me to remember that some seventeen or eighteen years ago he and I were associated together in some work of this kind. The diagram here represents very nearly the conditions which we had then. Our ring was some four in. (10 cm.) thick, something like five ft. (1.5 m.) high, and about 12 ft. (3.6 m.) in diameter. It was one of the large nickel steel rings used on the first of the Niagara generators. The interesting feature was that we got away from a delicate fiber suspension galvanometer, and could maintain a constant reading on a voltmeter, of a volt or two, for some time while the current through the primary was increased. Indeed it was increased at such a rate as to keep the reading on the secondary constant. As I recall it now, a period of something like ten minutes could be occupied in keeping a constant voltage on the secondary by slowly increasing the current flowing around the big ring.

H. M. Hobart: Years ago we used to make alternators and transformers less satisfactory and more expensive than they

otherwise need have been in order to keep the reactance very *low.* The present tendency is perhaps to make them still less satisfactory and more expensive than they otherwise need be in order to make the reactance somewhat ***higher*** than would conform to their natural characteristics.

My own opinion is that when we try to give a transformer or an alternator a high internal reactance, the result is a bad transformer or a bad alternator ***and a bad reactance***; and I think that generally the best economic solution of the problem is to make the transformer as good as it can possibly be from all standpoints and then if we need further reactance, put in a reactance as a separate external item. That seems to me to be substantially the conclusion at which Mr. Moody arrives, and I should be interested in hearing his comment on this summing up of the situation. Of course, as Mr. Moody has pointed out, the natural reactance will be higher, the higher the voltage of the transformer, and in the case of very high voltage transformers a considerable proportion of the desired reactance can be obtained in the transformer itself, without sacrifice of other characteristics. But the point to be emphasized, as it seems to me, is that we should design a transformer from the standpoint of heating and efficiency and mechanical strength, and let the reactance come whatever it will, and then put whatever further reactance we desire, ***outside*** of the transformer. The introduction of iron to increase reactance is a more undesirable means than it would appear at first thought. We usually estimate the efficiency of transformers or of alternators by summing up the segregated losses, and we do not take into account the so-called " parasitic " losses which we have at full load. These " parasitic " losses are liable to be considerably increased if we employ magnetic material in the leakage paths. Moreover the increased reactance obtained by the employment of magnetic material in this way, while present at moderate loads when we do not require it, (when, in fact, it is very undesirable), is not present to any appreciable extent under the conditions of short-circuit. This is because, for the enormous magnetomotive forces present in the leakage magnetic circuit at short-circuit, the permeability of iron is scarcely in excess of unity, the permeability of air.

M. V. Ayres: I would like to say a few words in regard to Mr. Moody's paper, more from the point of view of the designer of the substation than of the designer of the transformer. I would take issue with the last speaker in regard to the desirability of designing a transformer and then putting the reactance outside. It seems to me that in the case of the railway substation, where reactance is required for voltage regulation, the method of putting the reactance inside of the transformer fills a longfelt want. A separate reactance for the purpose is a great deal of a nuisance from the point of view of building and equipping a substation. It practically takes up a great deal more room then its mere floor area would seem to indicate, and requires arrangement and ad-

justment of other apparatus just on account of finding the space to put the reactance; and the wiring of the secondary is always rather awkward on account of the very heavy conductor used. Of course, it is true that the transformer with the reactance feature would not have as good efficiency at full load, but it would seem probable that it would have as good efficiency at full load as a transformer plus a separate reactance coil. If so, that is a sufficient answer to that objection.

As to the use of reactance in transformers for very high voltage circuits and in installations of very large kilowatt capacity, I do not feel able to speak definitely. I only wanted to make the point that for railway substations where reactance is required for voltage regulation, it seems to me that this would be a very great step in advance.

W. S. Moody: I am afraid that I was not very logical, in view of the title of my paper, in referring at all to these external reactances, and without cuts or illustrations it will be difficult for me to describe in detail any of the types that have been constructed.

Just what form it is best to use in a given case depends upon very many factors—the current that you have to handle, the voltage, whether they must be transported, and so forth. As yet there has not been much opportunity to test the relative advantages, for fortunately, short circuits do not occur every day, and so as yet we cannot say whether one form or another form will stand up best under such strains. It is well that more than one form is being tried out, and I hope that some time in the near future we will have enough data to show what particular form is the best for average conditions.

In the communication read from Mr. McConahey he pointed out something in my paper that was not stated as clearly as it should have been. He states that the magnetic shunts in transformers will not necessarily protect the windings from any eddy currents that would result from the flux passing through. I had reference in my remarks entirely to the extra flux that is created by the presence of iron. It is easy to see that the transformer must be designed so that if the iron was not there the flux would be sufficiently low so as to cause no appreciable eddy in the conductors. If that is so, then the addition of the shunts will create a much greater flux, and that additional flux will not cut through the copper as the flux density in the air and the copper will remain constant, because the magnetomotive force causing them remains constant.

The reason why iron cannot be used advantageously in devices designed to limit current on short circuit is simply because you have in a large transformer, even when the primary and secondary are well subdivided, ampere turns enough so that you would oversaturate the iron, unless so large a section cross be provided as to give too much reactance at time of normal load. Similarly in these current-limiting reactances that are external to the trans-

formers, for, under the conditions of short circuit, the flux in the air is well above the saturation point of iron. So there would be practically no greater flux there if iron was present.

The Chairman: Are the concrete forms that you wind the resistance on reinforced?

W. S. Moody: No. sir. We have never felt that it was safe to reinforce them, as iron or any other metal that might be used to reinforce them might heat sufficiently from eddy currents to crack the cement.

The Chairman: How do you insulate the coils on the concrete form?

W. S. Moody: The conductors are bare and insulated by treated wood, with asbestos as a heat insulation between the conductor and wood.

Malcolm Mac Laren: The only comment that I have to make is to emphasize what Mr. Chubb said about the extreme sensibility of steel to its heat treatment. Different samples taken from the same consignment may show widely different loss characteristics, if subjected to slightly different treatment and the laws which govern the various factors entering into the problem are so complicated that it will probably be necessary to gather a great deal of additional data before any systematic attempt can be made to generalize on the subject.

W. L. Waters (communicated after adjournment): Mr. Moody's paper gives a complete resume of the present state of transformer design as affected by the presence of internal reactance. It is also interesting as indicating how early engineers understood the effect of reactances on the operation of transformers. The explanation given by Mr. S. Z. de Ferranti of the effect of internal self-induction in limiting the secondary current and influencing the regulation of a transformer is practically as complete as that given by Mr. Moody. Mr. Ferranti's explanation was given 20 years ago when he installed his first constant-current arc lighting transformer operated by the magnetic repulsion of the primary and secondary windings, this transformer being almost an exact duplicate of the series arc lighting transformer as used today. The development of distribution systems involving the parallel connection of transformers on a lighting net-work resulted in engineers reducing the self-induction of transformers to a minimum, in order to improve the regulation; and as Mr. Moody points out, it was only when synchronous converters came into extensive use—about 15 years ago—that it was recognized that the presence of self-induction in the circuit had other uses than that of producing a constant secondary rent for arc lighting work. On account of the existence of patents covering the use of a special external reactance coil to obtain automatic compounding with a synchronous converter, the writer together with other engineers of the smaller manufacturing companies, considered the possibility of building transformers with a high internal self-induction. It was soon found that with the

comparatively small transformers then being used with converters, practically the only disadvantage of placing the required self-induction in the transformer itself, rather than in the separate external coil, was that it became impossible to adjust the value of the reactance after installation. The transformers with high internal reactance were somewhat cheaper, and the overall efficiency was about the same, as the increased eddy currents mentioned by Mr. Moody were offset by the reduction in the weight of iron in the transformer due to the modified arrangement of the coils, and by the absence of any losses in an external reactance coil. A large number of such high reactance transformers was built and operated satisfactorily with synchronous converters, and it is only recently, when heavy compounding has been required in connection with large transformers, that the external reactance coil has again become a necessity.

The use of internal onexternal reactance for limiting the secondary current in a transformer on short circuit is merely a natural development of the Ferranti principle, which is now found to be advantageous on account of the increased size of power systems; and I think one of the most interesting features in Mr. Moody's paper is that it indicates how early the theory and principles of transformer designs and operation were thoroughly understood. The great advance in transformer design and manufacture during the past 20 years has been in the details of construction and in the improved methods of manufacture which have made transformers for high voltage and large capacity a commercial possibility.

M. G. Lloyd (communicated after adjournment): The especial value of Professor MacLaren's paper lies in the fact that the observations have been carried up to the critical temperature, since the measurements of magnetic hysteresis with varying temperatures have been comparatively few and most of these have not been extended to so high a temperature. A large number of measurements have been made upon permeability, however, showing that iron and steel lose their ferromagnetic quality at this temperature, and that the hysteresis must therefore disappear at this point.

The results obtained by Professor MacLaren are quite similar to those obtained by Kunz[1], who in 1894 made experiments up to 800 deg. cent. with specimens in the form of long thin wires, the measurements being made by the magnetometric method. He made use of several varieties of soft iron and of steel, and one specimen of nickel. The results with soft iron showed a decreas- of hysteresis with increasing temperature, the curve plotted be tween these quantities being a straight line. Very nearly the same result was obtained with steel when the temperature cycle was repeated often enough to obtain constant values. With nickel the hysteresis fell off rapidly at first with increasing temperature, and afterward decreased more slowly. As the author has made

1. W. Kunz, *E. T. Z.*, XV, 194 (1894.)

no reference to any of the previous work on this subject it may be of interest to note some of the other experiments which have been made.

Wills[2] found similar effects with iron and tungsten steel, and Thiessen[3] observed the same general trend for several materials between minus 70 deg. and plus 100 deg. Some of their results are shown in the following table.

EFFECT OF TEMPERATURE ON HYSTERESIS

Material	B_{max}	Ergs per c.c. per cycle					Authority
		15°	100°	300°	500°	700°	
Iron	4000	1080	975	685	460	250	Wills
Iron	6000	2200	2200	1450	725	—	Wills
Tungsten steel (4.5%)	2000	9200	8900	5800	2200	—	Wills
Tungsten steel (4.5%)	6000	12000	11700	8000	3750	—	Wills
		—70°	20°	100°			
Soft wrought iron	2000	423	397	333	—	—	Thiessen
Soft wrought iron	5000	1720	1620	1520	—	—	Thiessen
Soft wrought iron	10000	5070	4600	4030	—	—	Thiessen
		—52°	17°	99°			
Crescent tool steel	14700	33850	31880	29600	—	—	Thiessen
		—65°	24°	100°			
Nickel steel (5%)	14900	43070	41860	39700	—	—	Thiessen

The work of Honda and Shimizu,[4] reaching down to the temperature of liquid air, is perhaps the most illuminating which has been done on this subject. They found that upon cooling Swedish iron the hysteresis decreases for low flux densities, but increases for high flux densities, and tungsten steel behaved in the same way. In nickel and cobalt, the hysteresis was always increased by cooling. A research by Waggoner[5] shows that low-carbon steel behaves as stated above for iron, while high-carbon steel behaves like nickel and cobalt. The change was least for a steel containing 1.1 per cent carbon. He also found that the ratio of hysteresis to coercive force was constant for varying temperature and varying carbon content.

The above results apply to hysteresis with alternating magnetization. Experiments in a rotating magnetic field were made by Fuller and Grace[6] and by Perrier.[7] Both sets of experiments show that the maximum hysteresis in the rotary field decreases with increasing temperature, and that this maximum is reached

2. R. L. Wills, *Phil. Mag.*, V., 117 (1903.)
3. A. H. Thiessen, *Phys. Rev.*, VIII, 65 (1899.)
4. K. Honda and S. Shimizu, *Proc. Tokyo Phys.-Math. Soc.* 2, III, 186 (1904.)
5. C. W. Waggoner, *Phys. Rev.*, XXVIII, 393 (1909.)
6. W. P. Fuller & H. Grace, *Phil. Mag.*, XVIII, 866 (1909.)
7. A. Perrier, Thesis, Geneva. (1909.)

with a lower flux density. Thus for iron at 580 deg. this maximum occurs at 10,500 gausses, while at temperature below 340 deg. it occurs at about 16,000 gausses. Since the saturation value is also reduced by increasing the temperature, it was to be expected that the hysteresis would decrease to zero for a lower magnetization and this was found to be the case.

Perrier worked with nickel, magnetite and three kinds of iron and concluded that the ratio of the maximum values of the two kinds of hysteresis was characteristic of the material and independent of the temperature.

One of the most recent papers dealing with this subject was presented before the recent convention of the International Association for Testing Materials and presented results which had been obtained in the Chemical Laboratory of the Schneider works at Creusot. In this case an automatic registration was secured of the magnetic flux due to a constant magnetizing field with variable temperature. These experiments showed not only the critical point mentioned above at which magnetism disappears, but also another critical point between 200 and 300 degrees, at which point there is an irregular change in the curve in the case of many of the steels used. The changes at this critical point are not reversible. The authors connect this critical point with the disappearance of magnetism from the iron carbide or cementite. A highly oxidized steel probably containing occluded gases shows in the cold state abnormal hysteresis and coercive force. This anomaly disappears at about 250 degrees and appears at a slightly lower temperature on cooling.

I regret to note the misleading statement in the opening paragraph of this paper, where the author states in reference to the paper presented in April, 1911, that "It was shown that there was no apparent change in the law governing the variations of the hysteresis loss with the induction for all temperatures from atmospheric up to near the point where the steel became non-magnetic." In the discussion of that paper it was pointed out by both Mr. W. J. Wooldridge and the writer that this statement was not justified by the experimental results.

Malcolm MacLaren: If Dr. Lloyd will refer to the discussion of the authors paper of April, 1911, he will find that no results were presented to show that the law governing the change in hysteresis with the induction was affected by the temperature. The only point which was raised at that time was whether in the case of high silicon steel there should not be a greater variation from 1.6th power law than was shown by the author's results, and it was pointed out at that time that the inconsistencies were largely due to the erroneous method which Dr. Lloyd used in deriving his exponents. Since the date of that paper the author had made further measurements upon the exponential values for high silicon steel which show a departure from 1.6 above 10,000 lines, but there was no indication that a change in temperature would affect these exponential values.

DISCUSSION ON "THE RELATION OF CENTRAL STATION GENERATION TO RAILWAY ELECTRIFICATION" (INSULL), NEW YORK, APRIL 5, 1912, AND BOSTON, MASS., JUNE 26 AND 27, 1912. (SEE PROCEEDINGS FOR JULY, 1912.)

(Subject to final revision for the Transactions.)

DISCUSSION AT NEW YORK, APRIL 5, 1912.

John W. Lieb, Jr.: The Institute owes a debt of gratitude to our distinguished fellow member from Chicago, who has presented such a vast and important economic proposition so lucidly and convincingly, and who has come before us and with such frankness and without reserve, has given us the benefit of the experience of his company, and of the advantages which have accrued to it from his far sighted and economical administration.

The address that we have listened to is of great advantage to us, and I think we may say, with some regret, that we are not often favored with such addresses before this body. Our problems, as they have been discussed here, have unfortunately been limited to problems of systems, and we have had here time and again, as you all know, pretty active discussions as to choice of systems. May it not be that we have wasted a large amount of energy and time on some of the details of the problem, of its minor construction features, and have let slip by some of the more economic and fundamental propositions? I think, therefore, that the Institute is fortunate in having had presented an address which opens before us some of the larger aspects of the engineering problems with which we are face to face.

Not having had these figures in hand before, which Mr. Insull now presents to us, I am unable to discuss them from the standpoint of detail application, and I shall therefore approach the subject from a rather general standpoint. The first thing that strikes one is the large economical advantage which all of the centrals tations referred to, speaking solely from the light and power generating standpoint, have achieved in attaining the rather important load factors that are here indicated. These may with advantage to us be compared with corresponding load factors which obtain in the lighting and power stations abroad, which have not yet entered the railway field. It will be seen that the lighting and power stations here have reached a favorable economic position as regards high load factors, and advantageous investment costs, which has been due to their stimulation within the light and power field of all possible uses of electricity. It is undoubtedly due to their energetic endeavors to cultivate the field that they have been able to reach the high load factors here indicated, also taking advantages of the diversity factor resulting from the different applications of their product.

Mr. Insull, in his work in Chicago, has demonstrated in a striking manner the advantages of also invading the railroad field, and securing the benefits of that further diversity factor which results from a combination of the railway load and the lighting load. It

seems to me that one of the significant features of these diagrams is the great advantage, rather difficult to estimate, which accrues from the fact that the lighting load, particularly in the morning hours, leaves the light and power stations with a very large element of spare capacity at a time when the railroads, and particularly the surface roads, have or are likely to have, an excessive demand. This feature is rather strikingly indicated in the diagram.

I wish to point another thing in relation to this subject, and that is the question of the systems. If we are in the future to obtain the economic advantages of consolidation of systems, the economical combining of these systems will be greatly facilitated if they are operated by a similar type of current. If we are to combine these systems and have 15 cycles for part of the railroad load, 25 cycles for another part of the railroad load and part of the lighting load, and then 60 cycles for another part of the lighting load, the problem will be very difficult of solution. The figures which Mr. Insull has given us as to the economic possibilities of the situation have a very important bearing on this debated question of systems.

Dugald C. Jackson: I desire to express very briefly my appreciation of the creative imagination of Mr. Insull. When I say creative imagination, I mean an imagination which conceives and puts into useful effect those things which are of advantage to the engineering and the commercial and the social world. I think it is not too much to say that Mr. Insull's work in the lines that he has presented in this paper has been of much moment to electrical engineering, and is now proving of moment, and will prove of greater moment, to the general social fabric.

The question of obtaining power conveniently delivered for any purpose, whether for locomotion, for lighting, for heating, for cooking, for mechanical power used in the shop—it makes no difference what the use is—this question of the delivery of power where it may be utilized conveniently and for the least cost is one of the most important matters before our modern civilization, where we have our peoples closely contracted within narrow limits in the cities, and it is only by working out the problem in the broad minded and comprehensive fashion that has been presented in this paper that we can make the cities, as they are growing to be, inhabitable places. This is one of the things that our economists have not yet thoroughly grasped. The practise of the engineers has outrun the theories of the economists. The economists have not been able to keep pace, and we are constantly as a consequence of that situation, having contests between the engineering world and the general world of economics; but it seems to me that presentations of this kind before engineering societies must be an aid toward bringing the economic views and the engineering views into harmony. The economists are trying to get at the truth and the engineers are working for the purpose of producing truths, and consequently they must ultimately get together.

Charles P. Steinmetz: The data given in the paper are complete and conclusive facts, derived from actual operating experience, and as such must stand unchallenged.

I wish to say that this paper from Mr. Insull is the most important paper read before the Institute to which I have listened for years, in that it announces the approach of a new era in the electrical industry, the change from the diversified electric generating systems or diversified classes of work, to electricity as the universal source of power serving the community, the territory, the state, and nation. The great and important feature of the paper is that these curves and data are not the conclusions of an enthusiastic engineer who tells us what can be done, but are an enunciation of the principles which Mr. Insull has carried out in making this system the greatest and most successful central station of the world.

Lewis B. Stillwell: I cannot claim to hold a brief for the railroads, primarily, my first experience having been more especially in the general field of power transmission and in the theoretical contemplation of these possibilities which Mr. Insull in Chicago has worked out into actual demonstration. I regard the paper as peculiarly important, for the reason that Mr. Insull is the one man who has had the courage to translate into action what others have realized in theory, somewhat less clearly than he, for many years.

It might be inferred from what has been said that there is another side to this proposition of indefinite and general aggregation of plants, and like every other question of engineering, there *is* another side of it. You will note, if you will examine these curves, that the advantages that accrue from the utilization of the diversity factor decrease rather rapidly as the size of the individual aggregated plants increases. It is a very different proposition when you come to put together two 100,000-kw. plants from what you have when you are dealing with a proposition which involves six-light and ten-light customers—you are running toward one of the limitations. One practical limit interposes itself in respect to continuity of service; another that we encounter is imposed by the diversity of voltage. Unfortunately, it is complicated very greatly in many cases by the fact that we have several frequencies in commercial use.

I should like to ask Mr. Insull a question which may bring out a useful answer. I understand that he contemplates the possibility of extending his operations to the northern half of the State of Illinois. In many of the towns of that state he will find 60-cycle apparatus used for lighting, and I would ask Mr. Insull whether in undertaking to light a town at a distance of 50 miles from Chicago, he would propose to do this directly from his transmission circuit, or whether he would regard it as necessary either to employ storage batteries or carry turbo-alternators or some other device floating on the line to overcome the difficulty which results from momentary interruption of service?

It is not so very many years since the Manhattan Railway Company bought the 5,000-kw. units now operating in the 74th Street station, and it is only seven years since the Interborough Company bought a number of additional similar units now operating at 59th Street. These units need not be apologized for. They are operating today and have been operating since they started practically without interruption. At the time they were purchased they were, in my judgment, the only wise thing to install. But at present turbo-alternators of the latest design have a steam economy better by 4 lb. per kw-hr. than that of the 5000-kw. engine-driven machines under conditions of constant load. Taking Mr. Insull's figures for Boston, New York and Chicago, I estimate that difference represents something over one million tons of coal per annum; in other words, the progress of the art within these comparatively few years, not more, say, than eight years, is such that the improvement in the prime mover has resulted in an economy in coal alone amounting to 30 per cent of the present coal consumption.

This is a factor which powerfully assists us in carrying out centralization. It offers another very good reason why we can afford, to a certain extent, and more rapidly as the years go by, to set aside the older apparatus in favor of newer and larger units and consolidation of these units.

Benjamin F. Wood: Mr. Insull has indicted the railroad men for not purchasing power. I am one of those railroad men. The Pennsylvania Railroad has here in New York and in operation a power station representing an expenditure of about $4,000,000. The total electrical work, exclusive of locomotives, represented an expenditure of about $8,000,000. If we could have purchased that power we would have saved investment of that $4,000,000, and if it could have been purchased at a rate the same as it is being sold in Chicago, we could have paid a dividend on the other $4,000,000 of about 6 per cent. We are not the guilty party.

Cary T. Hutchinson: In spite of the interesting curves which the author has shown us and his claim of greatly reduced cost of energy supply when concentrated on account of the so-called "diversity" factor, another aspect of the question obtrudes itself; that is, the cost of energy to the ultimate consumer. Great central stations may be able to supply more cheaply than smaller ones, but the final question is, will they do so? As far as my experience goes, it indicates that there is no willingness on the part of the central stations to sell energy for anything less than the maximum price, as determined ultimately by the cost to the consumer of getting equivalent energy from some other source.

We have all heard, for years past, of the very low cost of energy in Chicago, but, nevertheless, the rates of their power contracts, as published, do not indicate that the phenomenally low cost benefits the consumer. As is well known, the large railway

contracts are at the rate of $15 per kilowatt of maximum and about 4 mills per kilowatt-hour, amounting to from 6.5 to 7 mills per kilowatt-hour. Prices as low as these are obtained in Philadelphia, where the cost of coal is nearly twice as great and where no claims of great economy have ever been made.

It seems to me, however, that the argument for large savings due to the diversity factor rests upon a pretty slim foundation; the difference of from 5 to 15 minutes in the time of the occurrence of the maxima is a narrow margin, particularly when variable weather conditions are taken into account. The per cent of saving is, as the author points out, small although the absolute amount may be great. Engineers and business men should and do base their estimates on percentage variations and not on the absolute amounts. Five per cent is just as narrow a margin when it represents five million dollars as when it represents five thousand dollars.

Bion J. Arnold: I happen to know something about the conditions of the production of power in the Commonwealth Edison station, although Mr. Insull may not think I do, but I do know that it is one of the most economical plants in the world for the production of electrical energy, and that it is due almost entirely to the splendid generalship that Mr. Insull has shown in the management and his wisdom in taking advantage of the services of the fine staff of engineers he has associated with him, and through these means he has been enabled to develop a wonderful business.

It is a fact, however, or rather I think the fundamental question as brought out by his magnificent paper is based upon the fact that a company of the magnitude of Mr. Insull's is able to take advantage of the improvements in the state of the art, by being able to discard gradually the obsolete machinery and gradually introduce more economical methods of production of electrical energy than any single small plant can do, and the large plant can stand the obsolescence loss, as it were, which the smaller plant cannot stand.

The other point is, as Mr. Insull has brought out, that he is able to increase the load factor by taking advantage of the diversity factor, so clearly shown here in these diagrams, and in that manner make a given investment take care of a much larger territory and a much larger business. Assuming, therefore, that in the production of energy he has the same station cost, he can keep the capital cost lower, and can therefore sell his current cheaper than the smaller producer can produce it.

I have recently been called into a situation in one of the large cities in this country where the power producing company was endeavoring to sell power to the street railway company, in the city, and the price had to be approved by the city. This municipality is one in which the municipal ownership advocates are very strong. If I were to name the city, you would know it as probably the leading city of that character in this country.

Therefore, the fact that the municipality, having absolute authority to approve the contract, was a party to the negotiations, in fact had the vetoing power, ought to make this particular case of some weight in this instance. The negotiations proceeded to the point where the power company made a proposition on its regular basis, embodying a gradually reducing primary charge and a reducing secondary charge, depending on the quantity of energy consumed, so as to make the proposition acceptable to the railroad, and at the same time permitting any customer to buy energy at the same rate at which the company offered to sell it to the railroad company, provided he purchased the same quantity of power. The representatives of the city said, "Oh, we can produce that power for less than that price"—Mr. Hutchinson's point. It was finally decided to leave the decision to some outside party, and the party was called in. In a short time he figured out what the railroad company could produce the power for, installing a new station, up to date machinery to be purchased, and installed according to the most modern methods. These figures were determined and discussed in conjunction with the engineers of the power producing company, the engineers of the city, and the engineers of the railway company. The result was that the average figure submitted by the power producing company, the company that had the energy to sell, was accepted and embodied in the contract as being lower than the figure at which the railway company could afford to produce the power itself. The price was $\frac{3}{4}$ ct. per kw-hr., delivered to the substation of the railway company, coal $1.80 per ton, taxes, 1.5 per cent per annum, interest 6 per cent, depreciation at 5 per cent per annum, compounded, which is 3.02 per annum, paid monthly. That will amount to the equivalent of 5 per cent per annum. The purchaser pays this interest and depreciation monthly, and therefore the seller gets the benefit of the use of that money by putting it out at interest at 4.5 per cent and gets the full face value of the plant at the end of twenty years. The thermal efficiency of the plant is satisfactory, being 10.5 per cent. which is as good as any modern plant can be built for, although there is one in New York which shows an efficiency of 12.5 with compound reciprocating engines and low-pressure turbines, but this is an efficiency that is not attained very often. The investment per kw. capacity in the plant, however, must be considerably higher than the modern station can be installed for, so that its gain in thermal efficiency is probably offset by higher fixed charges.

Take the stations installed several years ago. Their thermal efficiency ran from 7.5 to 8.5 per cent. The modern stations run from 9 to 12.5, mostly running between 10 and $11\frac{1}{4}$ per cent. That is about as good as we can do when we start out today to design a plant and turn out energy for the purpose of running our railroads, especially in sizes of 10,000-kw. capacity. If we can go to 15,000, 20,000, 25,000, or 30,000 kw., we can bring the cost per kilowatt-hour down somewhat, not because the thermal

efficiency increases so greatly, but because the labor and capital costs decrease somewhat. The thermal efficiency of the plant, after you pass 10,000-kw. units, remains practically constant. The cost per kw., that is the fixed charge, might go down somewhat, because you could buy the larger unit for less cost per kilowatt capacity, so that you get a slight reduction in the fixed charge and a slight reduction in the labor cost, but the thermal efficiency remains practically constant, consequently there is not much chance for reduction of cost there.

Therefore the central station, built and operated as it is, with skilled managers, skilled engineers in every sense, and having an enormous investment, is able to take advantage of all these conditions and to keep increasing its investment by installing large units, but at small cost per kilowatt capacity, and thus keep its fixed charges down to a point below the point a private plant can reach. That is the reason why the large stations can sell energy cheaper than we can make it in small plants.

Mr. Insull referred to one situation in New York, viz., the New York Central, in which, he said, the engineers did not know that they ought to buy energy and the sellers did not know they ought to sell; all of which is largely true. It is a fact, however, that at the time those plants were installed, some eight or nine years ago, the thermal efficiency of plants was about 7 to 8 per cent, and at that time Mr. Insull was running turbo-generators, some of the first in the country, on some 24 lb. of water per kw-hr. He has advisedly discarded these generators since, putting in machines that are running on, say, 12.5 lb. of water per kw-hr. Those of us who built the stations at that time could not do as well as this, although we did buy machines at that time, which we installed, which produced a kw-hr. on 14 lb. of steam, and the next station we installed is doing it on 12 lb. of steam, so that we did not do as badly as some might think. We may have made some errors at that time, but the *main things* pointed out *now* as *errors* were *not errors*. They were decisions that had to be made due to the conditions which existed at that time. The central station was not in position to sell energy at that time as cheaply as it can sell it today. Therefore, we could not secure a price which would warrant us in buying the energy, hence we had to build plants. We did build the plants, and fairly economical plants, and one of those plants which is in existence today is the most economical railway plant in this part of the country, running on about 40 per cent load factor, so we were not very far behind Mr. Insull in that particular plant at that time.

Samuel Insull: Are those the same machines we scrapped?

Bion J. Arnold: No, you scrapped 24-lb. machines and we put in 14-lb. machines.

Samuel Insull: We scrapped a $17\frac{1}{2}$-lb. machine as well, made later than the machine to which you refer, and for which we paid a premium. I understood this machine was the same as you installed.

Bion J. Arnold: I want only to make this brief conclusion: I think Mr. Insull presented a splendid paper, and I am in sympathy with the policies he is advocating. In my capacity as chairman of the Board of Supervising Engineers, Chicago Traction, I approved the contracts the Commonwealth Edison Company made with the railroad companies in Chicago, and approved them because I knew we were buying energy as cheaply as we could make it. My advice to clients for some time has been, " Whenever you can buy current as cheaply as you can make it, buy it, and get rid of the worry of producing it; if you cannot buy it more cheaply than you can make it, then get ready to make it, and the man who has it to sell in large quantities will then come round and show you that he can sell it to you more cheaply than you can make it."

Frank J. Sprague: We are face to face with two important facts which are not altered by any minor discussion as to individual cases. First: That throughout the length and breadth of our country we are facing a continually increasing demand for power —increasing for two reasons, first, because of the inevitable increase of population, and second, because of the increasing uses for power. There is also the somewhat appalling fact, if we take account of the future, instead of being satisfied, as English directors of railways are, to let posterity take care of itself, a decreasing supply of fuel within the limits of our present ken. What does it mean? That we as engineers, not, perhaps, so urgently for the present, but for the future of those to come after us, must seek every opportunity to conserve our available power, now burdened with uneconomical production, and avoid the wasteful use of that power.

Mr. Insull has helped to blaze the way by the work which he has done in the Commonwealth Edison Company, in increasing the efficiency of power production and the variety of uses; and I look forward to the time when, in place of the thousand and one small isolated plants for different purposes, this country will be covered by great interconnected central stations, not individually magnified to an undue limit, but of such size as working efficiencies may demand.

If one should, on a cold day, in the city of New York, go to one of the upper levels of one of our great office buildings, and look northward, he will see countless steam jets in the air, every one coming from a non-condensing isolated plant, operating either electric lights or elevators or machinery of various kinds. Suppose, for a moment, we could blot New York out of existence and recreate it tomorrow, would there be one of these isolated plants in existence? Would we have the diversity and irregularity of production we have today? Certainly not. New York would be planned so that not only its light but its power, and a large proportion or perhaps all of its heating (and, mark you, heating is one of the greatest futures in the electrical field), would be supplied from a few great central stations.

It was only a short time ago that New York was on the verge of a water famine, and our Commissioner of Water Supply, Gas and Electricity informed us that the consumption of water was 125 gal. per day per capita. I wonder where the 125 gal. per capita went to. When I think of the great population of New York that goes out of it in the summer time, and the proportion whose use of water is restricted, I could not find that there was an average of 40 gal. per capita per day used in the necessary domestic requirements in the City of New York. That left something like 85 gal. per capita to be accounted for. Part of it goes to waste in leaks, but a great part of it goes into the sewers of New York, because the power plants of the city, other than its great central stations, are run as non-condensing plants. With these eliminated I imagine our per capita use in the City of New York would not be more than 75 gal.

I commend that proposition to some of the members of the Institute as a suitable subject of study and investigation.

Mr. Insull has raised the question of the lack of foresight of the New York Central in not arranging to buy the necessary power. We could not buy power at the time we arranged for the New York Central stations under any admissible conditions. But I desire to acknowledge the very great debt which we owe Mr. Insull, because when the committee of engineers representing the New York Central Railway went to Chicago, the first thing they did was to go to the power plant of the Commonwealth Edison Company, where the first 5000-kw. machines were being installed, and were not then, I may say, fairly in running condition. As I stepped upon the platform of one of these turbines I turned to my associates and said, "I care not what difficulties stand in the way, or what may happen here at this plant, the day of the reciprocating engine in the electric field where steam is to be used is past, the day of the turbine has come." The decision of the New York Central to adopt turbines was made at that time.

Charles P. Steinmetz: I wish to refer to something which has not been mentioned in this discussion, and mentioned in the paper only by implication in the introduction, although, I believe it is an important factor in the success of these big central stations. It is an additional diversity factor beyond that which Mr. Insull has mentioned, and that is the diversity factor of the engineering staff. A system as large as that in Chicago can afford to have in its employ high-priced engineers of the highest theoretical knowledge and practical experience and general ability, far beyond that which any one of the smaller component plants could have, and that, necessarily, must give the big system an advantage which none of the smaller ones could possibly enjoy. That is a diversity factor which is not approaching constancy with increasing size of the system. The thermodynamic efficiency may approach constancy, the diversity factor of load may approach constancy, but the diversity

factor of engineering staff does not approach constancy, but remains of the same value, no matter how large the system grows to be, and that is an advantage which the smaller systems cannot hope to vie with as against the big system.

Bion J. Arnold: One point should be added to Mr. Insull's plan, over and above all the technical propositions which have been pointed out. There is a broader question, which Mr. Insull foresaw before any other man I know of. I think we will all credit him with it. That is, he foresaw that the public service business is a natural monopoly. He reasoned thus: "I am entitled to a monopoly. I am willing to invest, for any monopoly, a reasonable total sum, but I want that investment protected. Protect my investment to the extent of six or seven per cent, or any other return which may be considered reasonable, and I will keep furnishing power and keep cutting down the cost of power to the point that will bring that return." That is the broad policy which has won the great success of the Commonwealth Edison Company in Chicago, combined with the great engineering talent of which Dr. Steinmetz speaks.

Samuel Insull: I think Mr. Stillwell asked me whether I would be inclined to operate a unit fifty miles from the base of supply in northern Illinois—I don't think it is possible to find a place where that would be necessary, although I have not had the experience to be able to state whether it would be a safe thing to do or not. I would have to refer Mr. Stillwell to some of the people more familiar with long distance power transmission than I am. I do not understand Mr. Stillwell's reference to large central stations.

Lewis B. Stillwell: What I meant to point out is this. As shown by your curves, the advantages accruing from the diversity factor, in consolidating plants with reference to their supply, decreases as the size of the plants which are aggregated increases. In combining 10-lamp loads you have a high diversity factor. When you get to dealing with large plants, and undertake to realize an economy by reason of putting together two 50,000 h.p. plants, for example, you do not get a great deal of advantage from the diversity factor under ordinary conditions. I think your curves bear that out.

I would ask you again the question that I endeavored to make clear in regard to this supplying of power at a distance. You are in a position to look at the matter from both sides of the question. The very practical question that presents itself many times to us, in the present state of the art, and the art is not young, is this—Is it wise to endeavor to supply all the lighting of a city, a city of 100,000 people, from a transmission line 50 miles long, or should we let the lighting alone and let that be taken care of locally?

Samuel Insull: I do not know that I can answer that question, because I have not had the experience necessary to enable me to answer it.

Lewis B. Stillwell: I understand you are contemplating doing what I have endeavored to describe.

Samuel Insull: No, I do not think there is any place in northern Illinois where we would be more than 20 miles from the source of supply. It does, however, happen that we are supplying a number of consumers 30 to 40 miles from the base of supply, temporarily, and it happened last summer that we brought coal from the coal mines up to Chicago and turned the coal into energy, and sent the energy down to the coal mines to help raise coal out of the mines. But those are isolated instances.

Lewis B. Stillwell: That is not the same point at all.

Samuel Insull: I really do not know. I understand it is being done on the Pacific coast. Personally I have had no experience in the matter. I think probably I would be inclined to try it, keeping my local plant as a reserve, possibly using it a part of the time, so as to save the expense of banked fires, and get a portion of my energy from outside. I would creep before I walked, I think. After I got confidence, later on, in the transmission line, I might finally dismantle the plant.

I stated in my opening remarks that the percentage of saving was low, but that that low percentage amounted to a very large sum of money. I simply picked out that illustration of diversity of the block of apartment buildings because it occurred to me that possibly there might be some gentlemen here who really did not understand what was meant by diversity factor. I am not a trained engineer, and it took me quite a long time to learn what it meant, and I thought there might be some here who did not understand it and would not care to confess it, and I thought I would show them the best and plainest example that I had.

I was dealing with the matter on a broad basis. Probably outside of the very large traction companies in Chicago, I am one of the largest purchasers of power in this country.

There is no steam plant I have been able to discover where people pay commercial prices for fuel where they can produce current at 2.5 mills. I cannot do it. If there is any engineer, a member of the Institute, who can design such plants, unless some one has a longer purse than the company I represent, I shall be glad to retain him.

In dealing with the situation I have naturally had to refer to New York. It is the subject uppermost in your minds. So I took New York as the basis of my figuring and backed it up by the results we have obtained in Chicago. But it matters not to me who is the owner of the generating plant and the primary transmission system. I do not care whether it is the local lighting company, whether it is the local railway company, or whether it is the steam railway company, the principle is the thing I am contending for. I am contending against economic waste. When I speak of "purchased power" I simply use that term because that is the term that has come to be used in the

industry as designating the difference between making your own power and buying it from some one else. I say again that I think it would be a great misfortune if, as the result of this meeting, or as the result of the agitation that is going on throughout the industry on this subject, some move is not made with reference to concentration of manufacturing and primary distribution. I think one is almost as important as the other.

There are some other serious questions of an engineering character to be decided within the next year or two on this subject. I do not know at this time what the limit of size of unit is that will add to the efficiency, or the limit to which we can go in the increase in efficiency of the unit. I have not been able to find out myself. I have consulted the best experts I can find on both sides of the ocean. The question of size of unit comes in very much in this question of concentration of production of energy. I do not think we have by any means reached the economical limits of the cost of production. I do not think it will be possible for any ordinary public service company, by itself, doing just its own business, to take advantage of the economical limit when we do reach it. I think it can only be done by an aggregation of production.

There are a good many things we can learn to advantage from our neighbors. I have been for a good many years in the habit of sending my engineers to Europe to see what they can find out. If you meet them on the train between New York and Chicago when they are returning, they will tell you that they are behind the times over there, and that we cannot find out anything from them which would be an improvement on our methods, but when we get the written reports of these experts we find that we get full value for the expenses of the trip. I do not know of any case on the other side where steam railroad electrification on any considerable scale has started and the railroad companies have built their own generating stations. They go a great deal closer into the economics of things than we do in this country. We make money more easily here, we have greater markets. We can take a lesson from their experience. I make one suggestion to the Railway Committee—Take the remarkable situation you have here on the Atlantic seaboard, with the greatest density of population in the small amount of territory between Philadelphia and Boston. Take Philadelphia, New York and Boston, stretching out as three fans, with places like the Connecticut manufacturing towns, and go along the Boston & Albany road to Albany, and then cross New Jersey, through Pennsylvania to the south of Philadelphia. Figure out the money that can be saved by putting all the generation and primary distribution of power in that territory under one ownership. I do not care who owns it, whether it is the railway company, or the lighting company, or the traction company but I venture to say that the amount of money you would save would not only be sufficient to build the transmission lines and the generating

stations of steam railroads in that territory, but, I think, would go a long way towards equipping the railroads themselves.

Hans Lippelt (communicated after adjournment): No doubt most of those who have read Mr. Insull's paper have appreciated the valuable evidence and facts brought out. The first impression produced is certainly favorable towards Mr. Insull's proposition of unification of power stations. After all, it has occurred to me to question an increase in efficiency and savings, by the means proposed, is really wanted. You may think that this question is absurd, because any saving of money is usually welcome at any time. I believe, however, that in this case the savings are to be paid for at too high a price.

Consider first the reliability. If for greater New York all the electric stations for light, heat and power and for railroads, etc., were united into one and a boiler would explode, be it by carelessness or bad will, who would guarantee that the fragments of the boiler would spare the vital parts of the power station? There have been cases where, through a much smaller break down than a boiler explosion, enormous damage to the power house was entailed. If, for instance, the switch-boards were destroyed, the whole big district connected to it would be without further supply of electricity. What would then be the consequences? Can you conceive all of them?

In case of a general strike, similar to the recent coal strike, or in case of war, would the big power house not be a great temptation for some aggressive people? Of course you do not expect a war here, so you may consider, if you like, your power house safe from such troubles. But for how many years can you guarantee such safety for your supply of light, heat and power, and for your railroads? May the railroads not be put out of business just when they are most urgently needed?

Moreover, I believe that with the realization of Mr. Insull's proposed scheme a legal reaction would set in, based upon the Sherman law. How would you be able to show that there is no "unreasonable restraint," in order to evade prosecution? Would not the trend of unification tend toward "restraint of trade" in electricity?

When I saw the slides, showing the present power stations, disappear and the others, showing the unified systems and common power stations, appear in their places, I felt that with all these power stations there had been wiped out many positions and opportunities for people who are compelled to offer their abilities and skill for just such opportunities to make their living. The vast scheme would not only affect the oilers of the machines, but all grades of employees from the oilers up to the clerks, engineers, managers, etc., would be affected. Would those who were told to go, praise the scheme as a wonderful stride forward in civilization? Would they?

It was remarked in the discussion that the great managing company could afford to engage "the best engineer," pay him a

good salary and have him devise the best methods and means. What is to become of the other engineers of reputation in this line of business? Is their talent to be wasted? The market for it will then be quiet and the choice small. With only comparatively few power stations in the country, where is the next best engineer, where are others, going to get their experience? Are you sure that the ablest one will get his opportunity to develop his capacities? Would the few men higher up always favor applicants on the basis of merit and thus insure the expected high standard of efficiency?

If unification of power houses is so economical, why then shall we not go a step further and wipe out not only the individual power stations, but the Pennsylvania, the New York Central, the Lackawanna and other railroads and make them all one? According to Mr. Insull's theory and, as stated in the discussion according to approved practical experience, the savings must amount to many millions of dollars. Yes, and to go beyond the limits of this horizon, why not save money by making the states of the United States one big state? Would you feel safe and justified in advocating such schemes, standing just on Mr. Insull's theory, or would you need a broader ground to stand on? Would you not discover new factors entering into the proposition and limiting the great hopes for a wonderful result, which should benefit all the people of this free country? It seems to me that the speaker himself had a premonition of the dangers slumbering in his scheme, when he spoke of the " courage " that would be required to realize such a vast thing. It will certainly be interesting to see when the first steps in this direction will be taken, and how many of them.

Discussion at Boston, Mass., June 26 and 27, 1912

Frank J. Sprague: It has been said that the Railway Committee has been somewhat inactive during the past year. I have purposely held it in that position. It seemed to me, in the beginning of the year, that we were in a state of development in respect to the three systems of railway operation, the polyphase, the single-phase and the direct-current, and that with regard to each of them there was a good deal to learn, and each had a good deal to demonstrate. Extensions along the lines of each of these systems were contemplated at that time which might make it possible for us to make comparisons which heretofore had been impossible. It seemed to me wise during the year to suppress a good deal of the discussion that had taken place as to " systems," that little was gained by its present continuance, but, that if we proceeded to determine the actual facts of performance as illustrated by those systems which were then in operation we would lay a basis for future progress which would be more reliable than anything else we could do at that time. It seemed to me that one of the first things to do in getting information was to secure the facts as to the cost of

power at the central stations; and in casting about to get authoritative statements on this subject, I found there were two sources. One was specifically a railroad source, or combination of railroad sources, the operation of the plants at Port Morris, Cos Cob, Westville, Marion, Jersey City and Long Island City, each of which was doing little else than supplying current for railway purposes. The other, of course, was the central station operation of the country as typified in Boston, New York and Chicago, perhaps to the greatest extent in Chicago, because there not only does the central station company have, in addition to the lighting load, a diversified supply of power to all sorts of industries, but also a very large railway load. So I appealed to Mr. Insull to prepare a paper on the question of the generation of power for electrical purposes, which he kindly consented to do, and also to supplement his paper by statistics relating to the railway conditions in Chicago, which are important.

Although the Railway Committee, as such, has been to a certain extent idle—its visible work is typified in Mr. Insull's paper—it has not been idle, through its chairman, in other directions. I have been charged with being an ardent advocate of this or that system, in a somewhat competitive way. I have stated sometimes that I was an agnostic, and I have hoped that there was some other means of arriving at results than by the somewhat accentuated discussions which we have sometimes had. So I have been centering my energies for the past six months on trying to bring about something of an *entente cordiale* between certain railway companies and the larger manufacturing companies, by which they would agree to take up some great railway problem, and present it to some acceptable technical commission whose members should be *persona grata* not only to each other but to the manufacturing companies and the railway companies. If the problem included terminal work, freight haulage, and suburban and through passenger operation, and extended over sufficient territory to embrace all kinds of railway contingencies, probably these men could divest themselves of any past prejudices which they may have had, and recognizing that both single-phase, polyphase, and direct-current applications have now reached nearly their normal limits of development, so far as motors and transmission and all those matters are concerned, could arrive, perhaps, at sound conclusions as to the future of electric railway operation.

It is my opinion that this proposal has somewhat advanced, and I believe that if any competent body of fair-minded men will divest themselves of their other activities, and confine themselves for some time to the consideration of a specific problem, they must arrive at one of two conclusions: first, that there is a definite trend of development in certain directions, or second, that the applications of electricity are so varied and its possibilities so catholic that while we are not confined to any one

system there are certain things which may and ought to be standardized.

I believe that such a body of men with all the facts before them would come to a common conclusion, no matter how much they differed in the past. I do not predict, at the present time, what that conclusion would be. The principle of the survival of the fittest will apply to the electric railway systems as to everything else.

When I took up Mr. Insull's paper I was very much impressed by two statements which I will quote. One of them begins on the third page of the paper: "The conclusion that I have come to is that the concentration of the production of energy, for all purposes required in a given area about any large center of population, would result in such a saving in capital, and such a saving in operating expenses, as to provide sufficiently for the generating capacity and primary transmission systems necessary to electrify the terminal systems and suburban service of all the trunk lines centering in and around that center of population (particularly is this true of New York), and such a saving as to yield very large profits, in addition, to the engineers and financiers having the courage to handle so great a problem."

The other statement is found on the first page, where Mr. Insull says: "Nor am I going to discuss what might be termed the technique of the electrification of steam railroads; that is, the special system that should be used, whether it should be done with one class of current or another, or one pressure or another. The system finally decided upon must be the one which fills conditions of railroad operation, and at the same time renders it possible for the railroad company to take advantage of the sources of energy supply already existing, as the railroad demand is only about 15 to 20 per cent of the total demand for energy in any community."

In Chicago there has been for a long time a popular movement for the electrification of the steam railway terminals. That movement was initiated very largely because of the smoke conditions which blanket that city close to three hundred and sixty-five days in a year. With some thirty-two railroads entering Chicago, and with a very diversified freight and passenger service, it goes without saying that if these several railroads should proceed independently, and each settle upon some independent system of electric application for its service, there would not only be an intolerable condition of confusion in the end, but there would be such a sacrifice of initial capital invested as to make electrification burdensome and impracticable. Until the investigation was made by the authors of the appendix to Mr. Insull's paper, the amount of power which would be required in the electrification of these railroads was practically unknown, but as we note the amount which is required, as set forth in the paper, we see that the average is exceedingly small, when we consider the size of the generating units used

today in our modern power houses. For example, we find here a record that the individual average load in kilowatts for freight service, in October, 1911, varies on these thirty-two railroads from a minimum of 100 kw. up to a maximum of less than 8000 kw.; also that the average maxima of all these loads in that particular month was only 72,000 kw., which is only the capacity of three or four modern generators. Mr. Insull pointed out the possibility of supplying power to these railroads. For that supply an individual power house to each road is simply out of the question, it cannot be considered. Group supply, that is, power houses which are intended to supply all the demands within a certain area, is the next step, and offers a gain in first cost and economy of operation. Centralized supply, centralizing not only power but transmission lines and diversity loads, offers so great an economy, not only of initial investment but in operating expenses, that it does not seem to me that there is any possible question but that the future must see that solution in Chicago.

I suppose the majority of those who read this have not seen the first report of the commission which now exists in that city. Sometime ago the railroads in the vicinity of Chicago, co-operating with the Association of Commerce, appointed a commission whose province it was to study the abatement of the smoke nuisance in Chicago and the possible electrification of the railroads. An elaborate organization was created, and the first product of the work of the commission, after a year's activity, is confined to the investigation of the smoke nuisance, how existing smoke conditions can be combatted and overcome. Electrification of the steam railways, so far as that report is concerned, seems a long way off.

How is that prospective delay to be overcome? By appeals to the prejudices of the railroads, or to those of the manufacturing companies—especially in view of the differences between the engineers? Surely not. It is my belief, however, that there is an effective procedure—that there can be created, between the railroad companies and the manufacturing organizations, an independent financial organization which, after due investigation of railways where electrification may be seriously considered, is prepared to go to these railways and say: "Gentlemen, you may not believe in electrification, and you may not care to take the necessary capital risk, or divert your capital from your other undertakings, and you may not be fully convinced of the financial returns which will come from electrification, concerning which others are more confident than you are. We are prepared to enter into a contract with you to operate your railway on the basis of supplying power for a period of years at a reasonable rate. We will also, if you desire, make a contract to supply on a basis of usage the rolling stock and equipment for your railway, leaving you to provide a right-of-way along your track for such transmission lines as may be necessary, and only such capital

investment as is required for the working conductors, or the possible provision of substations along the right-of-way if such be needed, thus limiting the capital risk of the railroad to about one-third of what would be required for individual operation." I am frank to say that that possibility is in the future, and it looks as if such a thing may come about.

Referring for a moment to the cost of power, I notice that Mr. Insull criticizes the New York Central & Hudson River Railroad management, and inferentially its engineers, for having installed power houses. We did not have Mr. Insull and his company to deal with in New York. We were face to face with the necessity of putting in a power supply which could not break down, or if it did break down we should have another one to fall back upon. Positive insurance of operation and ample supply of power were primary necessities, no matter what the cost, so long as electrification was to be undertaken, as it had to be under the law. The result was that two great power plants were installed for the New York Central & Hudson River Railroad, one at Port Morris and the other at Yonkers. The station at Port Morris is pretty well loaded, and had the project of electrification proceeded as fast and as far as originally laid out the Yonkers plant would be likewise loaded at the present time. But we did try to increase our load by offering to our friends a supply of power, provided the supply of power would be in accord with our own belief as to what was right and proper. That did not materialize, and the result was that the New York, New Haven and Hartford Railway built its own power plant. We had to build our own power stations because we could not get a proposition from anybody to supply power at a reasonable rate.

The output of the Port Morris, Long Island City, Westville, Jersey City, Marion and Cos Cob power stations varies roughly from 21 million kw. in 1910, in the case of the Jersey City station, to 159 million kw. in 1911 in the Marion station; and the power costs, according to the curves of the principal stations, run along at a very fair average. For the year 1911 the average cost of power at five of these stations was about 0.51 cent per kw-hr. at the station switchboard, excluding fixed charges, etc. The lowest average seems to have been at the Marion station, 0.45 cent per kw-hr. Those familiar with the cost of power at the Commonwealth Edison Company's plant, and even taking into account the difference in the cost of coal, an advantage which they have, will find that the average of 0.51 cent per kw-hr. is higher than is achieved at the larger station with large units, with a very diversified use. The Cos Cob station, for reasons which I have not yet been able to determine, runs from 45 to 60 per cent higher in power cost than the average of the other five, and varies considerably. That is a single-phase operating plant, but I do not know how much that has to do with such a variation between that and other stations.

We have here the statistical facts, but I do not wish to make any prediction, or come to any present conclusions as to this difference of 45 to 60 per cent between the average of five stations and that of another station. The character of the load may have something to do with it. The Cos Cob station ran only something like 27,000,000 kw. for the past eleven months, and if that is the reason, it illustrates the attitude which I have taken all along, that since there was an opportunity to buy power from an existing station at the time that Cos Cob station was erected, probably, so far as operation at the present time is concerned, it would have been more economical to have bought the power than to have erected and operated this central station.

H. G. Stott: I have read this paper with great interest and I have been trying to discover the hypotheses from which Mr. Insull draws his conclusions. As far as I can discover, his conclusions are based on the results obtained in Chicago. These results, it must be remembered, were obtained, not by combining first-class plants, but by combining in one or two plants the output from a number of practically broken-down plants which were just about ripe at that time for reconstruction.

To begin with, the railroads in Chicago were operating plants which were of antique design (several of them non-condensing) and had been allowed to run down, and necessarily operating costs were quite high, whereas the Commonwealth Edison Company had just concluded installing the most efficient apparatus that could be found on the market. It therefore had all the advantages of a modern plant as compared to an old plant. This, in itself, would probably give an advantage of from 30 to 60 per cent in operating costs.

Referring to Fig. 15 in his paper, the author says "This diagram shows you the result we have been able to obtain." The diagram does not show costs; it merely shows the difference in what might properly be called the load factor, which shows that they have succeeded in filling up a gap in the load. I have for a long time been trying to discover the relationship between load factor and cost. As the first approximation to a law governing it—an empirical relation—I find it varies inversely as the fourth root of the load factor. That means, as shown, for example, in Table III, where a comparison is given of the average of the load factors as 51 per cent but where, combined on one generating system, the total load factor would be 56.2 per cent, that if you use this rule of the inverse fourth root the saving in operation should amount to about 2.5 per cent. This, when applied to the data for the total annual load in the district covered by Mr. Insull's paper, which covers New York and the neighboring district of New Jersey, shows that the output is practically 2,000,000,000 kw-hr. per annum. Applying this figure to that output, we get a saving of $250,000 per annum, as against $1,000,000 in the paper, assuming a cost of 0.5 cent per kw-hr.

From this brief analysis, I have concluded that Mr. Insull must have assumed that the results obtained by any combination of plants would be the same as obtained in Chicago, irrespective of the condition of the plants, and on this point I take issue with him. You come to a point where the size of the unit used no longer affects this economy appreciably. For example, in a 10,000-kw. turbine unit, using high-speed modern machines, you get almost as good economy as you can in one double the size. When you reach a point where you are using that size of unit, very little is gained by increasing the size of the station. You make a slight gain by reducing what might be called superintendence or overhead expenses on that plant, but that is trivial and, being spread over the output, ought to have very little effect upon it. I have come to the conclusion that there is practically nothing to be gained unless you can change your load factor very perceptibly. When you get beyond a 50,000-kw. plant there is very little to be gained from an increase in size alone.

The diversity factor in railroad work, as we notice from the paper, is practically nil. Peaks, as shown by the load curves of the periods, are almost exactly coincident throughout the year. No matter how many plants you combine in one, the total installed capacity must be the same. Mr. Insull mentions here with independent plants for each road he would call for a reserve capacity of 50 per cent, whereas with the single combined plant he only calls for reserve of 25 per cent. I would like to ask him if he follows the same rule, and where any one actually carries 25 per cent reserve in a plant? With modern apparatus, 15 per cent reserve is, perhaps all that is necessary. One unit is considered ample when combined with the overload capacity of the other machines.

Another point on which I wish to take issue with him is the statement in regard to the saving on the distribution system. No matter how many plants you have, considering the question broadly, the cross-section of the copper required to carry the load is practically the same whether the combination is made up of two plants or forty plants. Each distinct plant will require a certain cross-section of copper, irrespective of the fact that it is in combination with others. I am speaking of the total cross-section, not the total length of cables. The saving in distribution in conductors which Mr. Insull has shown is not a factor of consolidation of plants; it is a factor of distribution of plants at better feeding points. For example, if we take the various plants, some fifteen or sixteen, around New York, and one came to an agreement with the other and said, "We will feed all substations or networks within two miles (3.2 km.) of our station, and we will agree to interchange power on that basis," you would obtain in that way all the saving it is possible to make in the use of copper, without combining them in one mammoth plant. In a mammoth plant the total amount of copper required would be enormously greater than in several smaller plants.

The old problem of finding the center of distribution for a given load is a familiar one, and it shows that the plant should be put in the center of distribution to effect the maximum economy in copper. The cross-section is practically the same, where you have one or more, except that if you have one large station, you will require a larger cross-section due to the increase in drop, on account of the longer feed.

I am sorry, also, that Mr. Insull has not told us, or given approximate figures, even percentages, if he did not care to disclose actual figures, of the financial result of this diversified load factor which is obtained by combining the plants. The question immediately comes up: Suppose a plant gives six mills per kw-hr. as the operating cost, and we are able to erect one which will operate on four mills per kw-hr. or less, and sell power to the other plant, is not the man who now has a plant obliged to amortize his investment in some way? For that investment stands on the books and represents collateral value for the bonds which have been issued for the construction of the whole road or system. If we write off that capital immediately, as we do when we shut down the plant, and virtually turn it into scrap, at ten per cent, probably, of the original cost—you are very lucky if you get that—should not the customer, who writes off that capital, share in the profits which he has enabled the manufacturer of power to make? Therefore, the profits apparently should be divided. That is a point of view which I have had brought out very forcibly in connection with some of our companies, that you cannot turn around and say, merely because you can supply power to such a company, perhaps, at 25 per cent less than the cost to them of making it, that therefore they should throw out their plant, because, obviously, they have nothing left to show as collateral for the bonds that that plant represents. The profits must be divided on an equitable basis between the company which makes the power and the company which buys the power.

In conclusion, it would seem to the speaker that the ideal solution of the power question is for each company to retain its own plant, thereby preserving its equity, and let an agreement be made by which each plant will supply *all* power within its own zone of economical distribution.

It is, of course, assumed that the plants will be modernized and kept up to the highest point of efficiency, for if the common exchange price per kw-hr. is put low enough by agreement, then each company will be forced to make its power as economically as possible.

William McClellan: It is well known that railroads may be divided into classes from the standpoint of electrification. Some roads will probably not be electrified until conditions very greatly change. For another class of roads a large amount of study would be required to determine definitely whether they ought to be electrified. There is a third class of roads which ought to be electrified at once if its managers could do so.

The first class of roads will have to wait for consideration until conditions change or until they perhaps become a part of a larger system and are electrified as a matter of general system economy. Among the doubtful class of roads there is no question that a larger and larger proportion of the doubtful roads can be electrified when our costs are reduced. By costs here we mean not only the direct costs of operation but also the cost of investment as reflected in the interest and depreciation charges. There is no question that if the financial test were applied at present the answer in many cases would be negative.

But where can this cost be reduced? Certainly we cannot expect electric locomotive costs to be much reduced. True, they have been higher than they will be in the future, especially when prices are standardized and larger quantities are manufactured. It must be conceded, however, that there will be no great saving in this item.

The third-rail system has been standard, more or less, for a number of years and its costs are now down practically to rock bottom. There can be no saving here.

The overhead high-voltage catenary system at first was very expensive but no one making an examination of what the New Haven road proposes to install now could possibly call it expensive in first cost or expensive to maintain. It may be safely claimed that no great reduction can be expected in this part.

I am not unmindful of the great saving brought about by electrification through the increased use of both track and equipment. It is not necessary, however, to discuss this here.

Where, then, shall a reduction in cost be looked for? If the above statements be true, decreased cost can only be brought about by increased efficiency. It is not surprising, therefore, that combinations are proposed with the idea of obtaining this desired increase in efficiency. For a number of years rights of way have been combined to make operation as easy and convenient as possible. As a consequence the railroads of this country make up one great network, all, or practically all, of the same gage.

In a way, there has been a combined use of equipment by through trains, but the only great example of this is the Pullman system. When we commence to study electrification there seems no good reason why there should continue to be the diversity of equipment which now obtains in these operations. There is no reason why a railroad desiring to undertake electrification should design its own type of cars, differing only in detail from the cars on an adjoining system. A group of railroads operating in any one general territory could well agree to have one type of car and one type of equipment, for each particular kind of traffic.

Mr. Sprague has acknowledged that he asked Mr. Insull to write this paper because he thought the capital investment might be reduced by having the power supplied from one general

power house for a large variety of uses rather than from separate power houses. I think this possibility does exist, but conclusions should not be jumped at too quickly. I am rather inclined to agree with Mr. Stott that we have gone somewhat far afield in this matter and have not given proper study to the question of substations. It should be remembered that the only reason for establishing our modern substation system, that is, one power house leading into a number of separated substations, is that such a system puts a better load factor on the power house than a series of power houses would have had, one at each substation. If, however, the time comes when increasing the size of the station does not decrease the cost of production, then it is almost obvious that the substation system need no longer be adhered to.

It is quite probable that the total cost of transmission from a mammoth station to very large substations might be in reality an added cost. Under these circumstances the cost of power at the point where it is used would be greater than if separate power houses, properly located, were established.

The reference to sharing profits between the large companies and the smaller companies buying power is interesting. Certainly the buyer in making his contract for power would have to see to it that the price he got was such as to permit him to amortize his old equipment and retire it in a given time. If this point be included it may be more difficult still for the large power houses to make a showing in those cases where amortization would have to be allowed for.

Percy H. Thomas: I do not know that I can add anything of value to this discussion, except to suggest that possibly one reason our railways are not more in a hurry to go ahead and electrify their systems is that they are waiting to see if some new development will not turn up, some new method of operation appear. We cannot assume that we have obtained the best solution of every problem. We have made great advances, but still there is the question, "If we wait five years more, may we not use a different system?"

In my opinion, while much may be said on both sides of the question as to whether a single central system can better supply power for all purposes than a number of independent systems, we can almost foretell the actual result by instinct—the trend since the industry began has been towards centralization. We cannot always state just where its superiority comes in, but taking all the factors into account, I believe that centralization of control is what we are coming to. I feel very sure that at least our local population centers ought to be supplied all under one management; it may be that the advantage is not primarily on account of diversity factor, it may be that it is not on account of load factor, but there will surely be found some basic reason for justifying this method.

W. G. Carlton: There is one point Mr. McClellan brought out in regard to pooling electric cars and locomotives. I think the

idea of pooling might be applied to the power stations, for example in New York City, and if what were done, then the idea of Mr. Stott, in regard to saving distribution expenses by assigning territory to any one station and letting that station cover the load in its vicinity, could be very readily worked out. It seems to me that, as far as New York City and vicinity is concerned, if there is any large saving to be made in the handling and distribution of power in a wholesale way, it has got to be done by "pooling" the power stations. As to the manner in which that can be best worked out, I have nothing to suggest at the present time. I do not, however, believe the time will ever come when it will pay to build much larger power stations than we already have in some cases in New York City.

Calvert Townley: This question of the concentration of power in large centers, which is the underlying thought in Mr. Insull's paper, is, as he himself states, not a new one. It has been studied for a great many years not only by engineers but by the financial men interested in properties which supply electricity. Mr. Insull ably states many reasons why it is cheaper to generate a large amount of power in one station rather than smaller amounts of power in several stations, but he does not prescribe any limitation to this concentration process.

Suppose we carry that argument to its logical conclusion, without any limitations at all. If it be true that it is better to generate all of the power in Chicago or in any other large city, in one big station, why is it not true that all of the power in the suburban territory around that city should also be concentrated, and extending the argument still further why is it not true that all of the power required in the state, or in a group of states, or in the United States, if you please, shall be generated by one station located in Chicago?

Of course the absurdity of that conclusion is seen at once when it is stated, but it is necessary to bring out and strongly emphasize this point that any treatment of the problem of power generation is incomplete and faulty which does not also fully consider the question of distribution.

Certain economies referred to in the paper are obtained by increasing the size of the generating units. Others result from a higher diversity factor, and in many cases savings may be effected up to a certain point by combining into one the several distributing systems. As Mr. Stott points out, however, little is to be gained in operating economy by increasing the size of generating stations beyond a certain point, so that in considering a power supply of the magnitude of that under discussion the argument for concentration to secure operating economies has but a very limited application.

Mr. Insull's paper lays great stress on the improvement in the combined diversity factor over the several individual diversity factors. Mr. Stillwell pointed out, in the discussion which was had on this paper in New York, that as the size of the power

stations which are combined increases, the probable improvement in diversity factor decreases. This would seem to be almost a self-evident proposition even if it were not supported as it is by the very complete set of curves given in the paper. Having therefore reached a limit in saving due to increase in size of the units or stations which are combined, and having stations so large that their combinations will show but very little if any saving, in the diversity factor, it becomes difficult to find good argument in support of further concentration.

A comparison of the two maps of the city of New York and surrounding territory given in the paper, one showing the number of stations now installed, and the other the number which ought to be installed, shows that the author does not suggest combining all the stations into one, but believes several are to be preferred. The reason for retaining several power stations, instead of concentrating the production of power in one station, is not given in the paper, but it is a fair assumption that the author's examination of the local conditions indicated to him that the possible economies to be effected by further consolidation would be more than offset by the increased fixed charge of an enlarged distributing system and the losses to be expected therein. In other words, we have here simply another confirmation of the well known principle that each problem has to be studied by itself. The uses of the power must be considered, and the territory over which it has to be distributed, and whether one power station is best or two or three power stations, or any larger number, and whether one voltage or another, or one system of distribution or another, is to be preferred, and how many substations should be installed, are all engineering problems—those are what we are in business to solve. If problems of this character could be settled by rule of thumb many electrical engineers would be out of a job.

I do not wish to be understood in any sense as opposing concentration—I realize the benefits of it but I do not think we ought to accept the deductions of this paper as having as general an application as might readily be inferred unless the limitations are clearly understood.

While it does not exactly bear on the subject of this paper, my friend Mr. Sprague in his opening remarks asked the questions, why did not the New Haven road buy power from the New York Central, instead of building its own power house, and why is the cost of generating current in the New Haven power house higher than it is in the New York Central power house? I can answer the first question at once—the New Haven road tried very earnestly to buy power from the New York Central road but the New York Central quoted 2.5 cents per kw-hr. as its lowest price. It finally said that under some very favorable conditions it might be willing to reduce that price to 2 cents per kw-hr., but beyond that it was absurd to talk of any reduction. It was necessary for the New Haven road to

have power at a certain date. It could not wait to conduct long negotiations, to see whether, by bargaining, it could get lower quotations, and it believed it could produce its own power for much less money. That is the reason why the New Haven Road built its own power station.

As to why the cost of generation is higher at the present time I have no figures before me, but I do know that the New Haven road load factor is very low. The peak demands are high compared with the average consumption of energy. This is a condition which was fully expected, because the electrification which the New Haven road has completed so far is only one step in a general scheme. The New Haven road at the present time is proceeding to extend its electrification from Stamford, 33 miles (53 km.) from New York, to New Haven, 73 miles (117.5 km.) from New York. Further future extensions are probable. It has electrified and will shortly operate the twelve-mile (19.3 km.) six-track branch from Harlem River to New Rochelle over which all its freight passes. The same power house is also soon to supply power to the new road, the New York, Westchester and Boston. The load factor undoubtedly will be much better when these additional loads are put on the station.

Mention has been made of the necessity for providing a sinking fund to amortize the plant cost when a company which has heretofore generated power proposes to abandon its plant and buy power. That point is well taken, but it must of course be remembered that the present demand on any station is an unsafe guide. One of the problems in supplying electric power is not only to get enough power now, but to keep on having enough power hereafter. The load has a habit of increasing, sometimes very rapidly, and that calls for additions to these power houses, and requires additional capital. This fact is often very favorable to concentration. It may well be that the directors of a railroad which has enough power for its present needs may be most reluctant to provide additional capital every few years for power house extensions, and if a large central station company can afford to supply all increased power demands, thus avoiding the necessity for such extensions, the amortization will then be limited to the present investment, while, for increases, the sums that would be reserved for this purpose are available for somebody's profit.

S. D. Sprong: I will refer to just one matter in Mr. Insull's scheme. There are four generating stations in Chicago as shown in Fig. 19, which is hardly a unified system.

W. S. Lee: I rather fear that the membership is drifting into the idea of getting too big units, having only one power station. In my opinion that is not the practise which we should follow in the problem of the centralization of power. The idea of putting everything into enormous units, a little bit larger than anybody else has, and putting it into one spot, will get us all into trouble. Mr. Stott referred to cross-sec ions of copper being the same,

whether it is run from separate stations or from a combination of stations. That is true, but our distances are becoming longer, and that would increase the size of copper. There is no question that the railroad demand in connection with the public utilities, as we usually refer to them, such as street railways and lighting plants, is one that calls for enormous blocks of power, and the demand is likely to be in one spot at one time, and in another spot at a different time. An arrangement is preferable of large stations, or central stations, at different places, and then some interconnection between them, so that in case an excess amount of power is required, one station can assist another.

I am not familiar with railway operation, but that is just exactly what we are doing in the case of power transmission. We are finding that it is an operating problem, and that it is wise not to have our stations too near together, nor to have too great an amount of power in any one spot. We have two power houses quite close together in one case. We have two of our largest plants located on one river in North Carolina, while we operate also on three other rivers, with a total distance of 300 miles (483 km.) apart. We find that these plants in different parts of the territory, with a connection between them, take their load satisfactorily in their respective sections, and further, are able to assist each other in case of trouble. I think centralization of power should not be considered on the basis of enormous stations, grouped in one spot, and everything emanating from these stations, but rather large units in different parts of the territory, each so placed as to carry approximately its own load, and also interconnected to take the shift from one to the other, and assist each other in that way.

Frank J. Sprague: I think the discussion has taken a turn which is hardly justified. I do not understand from Mr. Insull's paper that he recommends concentration in the largest possible station, with the largest possible units, for the power supply of an unlimited district; that would be poor engineering and bad business judgment. With any distribution of power, in any given field, it is perfectly feasible to determine how many stations should be erected, where they should be located and the method by which they should be operated to get the most economical results. Concentration of power in a station should go so far, and only so far, as calls for the use of units of reasonable size, in reasonable number, and with sufficiently diversified service to get a good load factor, and then as the area increases the number of stations should be increased; as Mr. Stott has pointed out, the natural and inevitable result is the interconnection of these stations with each other. Mr. Insull does not hold that all the power stations even in Chicago, or all the power stations in New York or any any other place, should be concentrated in a single plant, and I do not believe any engineer would agree with him if he took that stand; in fact his own practise is opposed to this view. Stations should represent

such a capacity as will insure a reasonably efficient operation, and cover area enough to provide a proper diversity factor. The gas and electric companies combine loads on the various stations, and must necessarily do so.

The point I do not want to get away from is this: Our object as engineers and members of the Railway Committee, and my desire as the chairman of that committee, is to increase the electrification of railways now operated by steam power. That is not a problem of concentration of antique plants, it is one of the creation of new plants, the taking up of a new problem. I have pointed out the fact that a railway load varies from a few hundred to many thousand kilowatts. With such variations, and the necessities of reserve power, can any engineer hold that railways in the same district should be run by individual central stations? Would any one say that their loads should all be combined in one station because they can be handled by 100,000 kw? I doubt it. But I do say, let there be here a station and there a station, each of them having a sufficiently large capacity to take care of a reasonable load, and then let there be an exchange of power between these stations.

Referring again to the New York Central and the New Haven plants, I was not party to any question of the selling cost of current in that case. As an engineer, I did recommend that the New York Central should sell, up to the capacity which it could spare, current off its busbars, equally from all phases, to be used in a motor-generator substation. This latter condition was opposed by the new Haven officials.

So far as the cost of power is concerned, perhaps if the New Haven Road had been in the same position as the New York Central it would not have given a central station price exclusive of all other factors, but that does not alter the fact that both stations, Cos Cob and Port Morris, and Yonkers also, could be run for less money if they were under one combined management or ownership, and interconnected where practicable. Take those stations out of the ownership of the railroads, and turn them over to a private corporation which would give a guarantee that it would supply ample power to each of these railway companies, including power for a dozen requirements in the Bronx and all through that section, and they could supply power to both roads for much less than the New Haven power is costing and possibly for something less than the power costs the New York Central.

I noticed that in the Jersey City station, where the load was only 21,000,000 kw. last year, the cost of power is very much less than the New Haven. I do not know why that is so, but I should like to know. There is no such disparity in cost as the relative loads would indicate.

W. S. Murray: As I understand it, there are two matters that are not clear to Mr. Sprague. The first one is the question of the wisdom of the policy of the New Haven in having elected

to build a power house of its own, rather than accept the power from an already built station adequate in size to take care of our needs. I think that matter was very clearly explained by Mr. Townley. The reason he gave was that we found we could build a power station and supply our own power at a much better rate of cost than the rate we could negotiate with the New York Central and Hudson River Railroad Company, and that was done.

As to the second matter, the cost appearing in the tables that Mr. Sprague has referred to, showing that the rate of generation at the Cos Cob station is higher than the several other stations mentioned, that is quite correct. I have never tried in any way to put a restraint on the presentation of data available in our railway work, but I have rather strenuously objected to the assembling of these data upon a comparative basis, because the conditions of generation at the Cos Cob station are so absolutely different from those involved in the other plants with which these data are compared. However, I yielded to the publication of the data simply because I did not feel that there was anything to be concealed. But I want to straighten out Mr. Sprague on this matter, because I know he has a great deal of confidence in the single-phase system, and I do not want to have him feel that this confidence has been misplaced, as a result of not going fully into an analysis of that situation.

Now the reasons why the costs of the Cos Cob generation are higher than the others are these: First, the Cos Cob station has an extremely poor load factor at present. I think it can be said without doubt that the load factor of the Cos Cob station is the worst in New England. There is nothing that is very disquieting, disturbing or disagreeable about that. The station, of course, has nothing to do with it. No matter what type of station be put there, it would be subject to the same load factor. That load factor exists, and therefore you must credit the station with having a most difficult situation to deal with so far as economical output is concerned. That is the principal reason. Now, it is compared, for instance, with the New York Central station, which has a very low rate of cost of generation, and what is the reason? Simply that there are installed upon that system storage batteries equalizing the generator load throughout the whole day. But we must not lose sight of the fact that while the cost per kw-hr. generated may be lower, the storage battery system requires more kw-hr. generated for 24 hours for a given train schedule than a system not employing storage batteries, such as that, for example, of the New York, New Haven and Hartford single-phase system.

Stated in another way, how much integrated power is required every 24 hours, to operate a certain train schedule? When you have sifted the matter down you find that the number of kilowatt-hours required per train ton-mile propulsion is lower at the Cos Cob station than at any other power station handling heavy electric traction.

Besides that, I want to draw attention to the fact that the

Cos Cob station, when first laid out, was laid out for expansion and its expansion has now come. These data have been circulating for some time between the companies, and quite rightly, but during this whole period, in which the rates have climbed up, Cos Cob has been upon a construction basis, rather than upon an operation basis. Take a station that has the end of it knocked out, and a new extension, of more than 100 per cent, being added to it, furnishing steam to the contracting plants surrounding it and its main turbines operating many times on a noncondensing basis, naturally if all this power is not represented in the divisor the rate must be high.

These are some of the reasons which show that the rate must be higher. If you come to me a year from now, in June, 1913, I can tell you another story. I will not have storage batteries installed in the plant, they never will be necessary, but in the place of these storage batteries there will come a different kind of means to bring a very even and more efficient load. In the valleys of our present load will be placed a magnificent freight load changing our very peaked condition of load curve and producing an excellent load factor. Besides that, all of the power that is to be generated at the Cos Cob station is not to go to train propulsion, but some of it is to go to the trolley roads and the lighting companies which the New Haven company owns. This explains in a way my demurrer to having these tables circulated, simply because they do not show the final results.

It is exactly the same way with the construction. In about a year's time, when the New Haven road can say it has under wire 550 miles (885 km.) of track, and has a complete division running by electricity, which is not in any way associated with steam, and every wheel west of New Haven is turning by electricity, when that time comes valuable data will indeed be at hand.

William B. Jackson: I feel that this discussion of steam railroad electrification is extremely desirable in connection with the paper under consideration, and I feel that Mr. Insull's analysis has brought out clearly the factors controlling the situation, for we have right here, in the case of the New Haven road, an instance of a plant taking care of a certain kind of service wherein the costs run high, and we must all admit it, from what Mr. Murray tells us. The plant will eventually take on different kinds of service which, in this case, will have an extra large diversity factor, and eventually bring his plant to be one of the best, so far as the diversity factor is concerned, and, let us hope, so far as the cost of production of power is concerned.

It is an interesting fact that a person is prone, in the consideration of a paper, to be influenced by the title, but in this case the title is likely to carry him far afield, because here the case of the electrification of steam railroads is an important factor only as it adds to the power plant, enabling the power plant to cover large areas, or to supply all of the service in large areas, and to

supply additional power which will improve the load factor and thereby improve the cost of generating the power. The alternative title that Mr. Insull suggests for his paper. " The Generation and Primary Distribution of Energy for Given Areas," is a big subject, a magnificent subject, and includes as one important factor this matter of electrification of steam railroads, as one of the services. We must also appreciate and have it clearly in mind that there is no suggestion of concentration of power in great power houses, for the reason that even though we follow out the suggestions which the paper contains, we will never concentrate in one power house more than can be economically carried by that power house. The paper is a splendid plea for the concentration of all electric service for any district which may be economically supplied from a single power house in the one power house, thereby securing the advantages of obviating the need for duplicate transmission lines and duplicate substations, and taking advantage of the improved load factor which Mr. Murray has pointed ou; to us in the reduction of the cost of electric power. Nobody, I believe, can take exception to that general principle, that if we are to provide power economically in this country we must get rid of the conditions where two or three different generators, parallel generators, are supplying the same sort of power.

We must also go further. In thinking of this paper, we are prone to think of it as applying merely to such great centers as the city of New York, Boston and outlying territory, and Chicago and its outlying territory, but we must recollect that the considerations in this paper take into account just as clearly the conditions around the smaller centers where, by bringing together into a single power plant all services of energy which are now or shall be later supplied by electricity, we are likely to get very important advantages, from the standpoint of less cost per kw. of construction of plant, and less cost per kw-hr. of output of the plant, and a tremendous improvement that is possible in the matter of general management and the other general expenses, which must take into account the physical operation of the plant, the policies which are to guide the service of the electric power in the districts under consideration.

We must also go a step further and appreciate that if we are to follow out logically the plea of this paper we must not only have these plants properly located and of proper size to carry all of their power, all of the electric power in their district, but we should also have them so located and inter-connected that satisfactory correlation is possible between the operations of the several plants, whereby there are undoubted gains to be obtained.

Lee H. Parker: I have already stated publicly that I believe all of the power required for the transportation facilities in Boston and its vicinity could be furnished by one large company. I believe that the steam roads within the Metropolitan District, when electrified, might have their power supplied, either by the

present Boston Elevated Railway Company, or some other large transportation company, which in turn could be amalgamated with the existing power and lighting company. I cannot see any good reason why the comparatively small amount of power required for the electrified steam roads should not be successfully and economically handled by any one of the large power producing companies in existence here in Boston today.

C. O. Mailloux: As engineers we must appreciate the fact that circumstances alter cases. Guided by that principle, one would see, offhand, that it would make a great deal of difference what the circumstances were in determining what the decision must be. There are certain fundamental principles which serve to guide the engineer when he looks at things from an economic, and also, perhaps, from a financial point of view. From the standpoint of the conservation of energy, and of capital, and of everything else (which is one of the live questions of the present day) it is far better that we should specialize—that the one who is producing electrical energy should produce electrical energy only, and sell it, and produce all that he can, while the man who is producing "transportation," or who is dealing with the "railroad-economy" side of the problem, should confine himself to that. But here, again, circumstances may alter cases. There are many cases where it would be far better that they should be combined, and there are great advantages, intrinsically, in doing that.

In connection with the development or new electrification of a traction enterprise, it would certainly be, in many cases, very useful and very convenient if one could detach the production of power from its utilization. Take, for instance, a project involving $10,000,000. If it is based upon the production of electrical energy by the company that is going to develop the project, one must include, in the cost of equipment, from $1,000,000 to $2,000,000 or $2,500,000 for the generating plant. Hence, in a case like that, if power can be procured from an existing power station a project can do away with a certain amount of financial handicap, from the very fact that it is able to get along with less capital at the start. We all know that the new project finds it hard to enlist capital; it finds it difficult to show a return on the proposed investment; but, even if it can show a return on the whole investment, the problem of financial feasibility and realization is greatly simplified if the total amount of capital asked for is reduced, say, 15 to 25 per cent.

In a case like that, therefore, the possibility of deriving the requisite supply of electrical energy from a central source of supply, such as is contemplated and advocated in the paper of Mr. Insull, may be of great value. In the first place, it would obviate the necessity of capital being invested in two, three or more "lumps" for the generation of energy; which means higher efficiency in the production of energy, also lower cost and lower managing expenses. These are centralized and correspondingly reduced, and from the standpoint of the man who is

interested in the purely transportation aspect of the problem, it simplifies the problem, because it necessitates his raising less capital and undertaking less financial and other responsibility.

One can see that the man who is interested in a new project, if he can buy power, can afford to pay, not only what it would cost him to produce it, but just a little bit more, in other words, he can afford to some extent to capitalize a part of that responsibility or a part of the difficulties which he would experience and would need to overcome in producing and procuring the necessary capital himself for the erection of a power plant and the production of the power. Hence, admitting that he were able to produce and procure the capital, if he can avoid the necessity of it, it is somewhat to his advantage to do so; and he can afford to pay a little more for it. However, as already stated, circumstances alter cases. The preceding reasoning is not always true. Take projects which are financed by large concerns, which are able to raise any amount of capital that is required—they find it just as much to their interest to employ capital, and keep it active, and make a return on it, for electric lighting or for power, as for transportation. In a case of that kind, therefore, the possibility of buying power is not of so much interest; but in the case of smaller projects, it is generally a factor of the greatest importance.

As these smaller projects grow and develop and extend, a time is reached in their career when most of them would find it to their own interest to produce their own power, and fortunately, when they have reached that stage they have "made good," so to speak, they have demonstrated their usefulness and have obtained from the public their "certificates of public utility and convenience;" and they are then able to enlist capital on much better terms and to much better advantage than they would have been in the first place. There are both of these classes of projects, and one general solution will not fit both classes.

It is a very instructive and useful thing, however, for this Institute to have had placed before it so clearly and effectively the possibility of the supply of power over large areas and over large districts from one centralized source. We must, of course, understand that in using the term "centralized" we do not necessarily restrict ourselves to *one* station. No one, in the case of a very large district, or a district in which the density of services and the total amount of current consumed was very great, would consider "putting all his eggs in one basket." It would be very much better to take a certain maximum size of plant, and to build two or three or more of them, connect them together, and use them in such a way as to obtain the best result, including a certain factor of insurance against breakdown.

I wish to emphasize the fact that there is a great advantage, to those who are interested in the newer problems in which public utilities in the form of transportation and lighting are concerned, to have placed before them the possibility of studying

the modern conditions of the supply of electrical energy, without being compelled, at least at the start, to go into the business of producing that supply themselves. It is a great thing to be able to specialize, and to find that some one else is specializing in a way that enables you to benefit by what he is doing and to save yourself some trouble and some expense.

P. W. Sothman: The whole question as presented in this paper is of universal importance, and is, at the same time, a question which cannot be dealt with by means of any fixed rules. I believe that the conditions of each problem will furnish us with certain guides, which will enable us to do the best thing that can be done in that particular case. As an illustration of the present subject, it was thought for some time that power plants should be concentrated as much as possible, and even placed under one roof; but it is my opinion that we can go very much too far in that direction. Experience with several accidents in recent years has shown that it is not the best policy to put too many eggs in one basket, and I do not believe that we shall ever be able to use a general rule which will tell us to do a certain thing in any particular way without involving a study of the project from beginning to end, and from all points of view, that is, from the commercial side as well as from the engineering side. Unless we can make such a thorough and independent examination we are not practising engineering at all, but are still the tools of the financier or the banker, or of some commercial interests which are using us for the purpose of filling their pocketbooks.

We must be stiff-necked and say: " The engineering problem of your system or in connection with your project is so and so," regardless of the fact that the satisfactory solution of the engineering problems does not necessarily warrant an equally fortunate commercial possibility, in which case engineers of today are only too often turned down by their financier with the comment, " that engineer is no good. I will have to get another one."

In my opinion great advantages can be obtained, and have been obtained, in the consolidation of railway loads with commercial loads. The load factor of a certain railway near Toronto, which we connected up just a year and a half ago, was a very poor one. The load diagrams of this railway were studied at some length, and we started in to help the company a little by cutting out certain trains at certain hours. The trains cut out were mostly freight trains, and these were handled during the night time to a great extent, but a small freight service was arranged to fill out the gaps during certain periods of the day.

The success of this move was somewhat surprising. The railroad was, previously, taking an average load of from 850 to 900 h.p., with peaks running up to 1700 h.p., and because of the educational work we were able to do, effecting a readjustment of the freight train schedule, and otherwise telling the company where its practise was not right, and how to improve it, the maximum peaks, I believe, do not now exceed 1200 to 1300

h.p. I am a believer in education, which, if coupled with fairness, can accomplish very much. If two men get together they can always thresh out something, and if both have a disposition to be fair and to meet on mutual compromises they can generally achieve good results.

In Europe the distribution of power for railway and commercial uses has been done largely in the last few years by the use of storage batteries. When I was over there last year I was very much surprised to see that a number of power stations had succeeded in almost entirely eliminating their peak load, that is, the curve of consumption was kept as straight as possible. This is a condition which has not yet been attained to any great extent in America. I have found that in order to accomplish this, different kinds of mixed systems are used abroad—sometimes the cars carry storage batteries which supply the load at certain periods, and sometimes one finds second trolley wires which are used for direct current in times of emergency, all of which gives a good flexibility.

I must admit that such installations would not receive approval the first time they were presented to a company in this country, but when you figure out the whole scheme, based on continuous service, or, in other words, when you figure out the real value of absolutely continuous service, the cost of generation, which is only a part of the whole, will fall down reasonably low, and should convince your customers of its desirability. There is no question but that continuity of service is one of the leading factors in the supply of electric current.

I feel that the question of the electrification of steam railroads is 99 per cent a commercial one. As to the engineering phase of the question, there is no doubt that it can be successfully done, but, as stated above, we must study each case on its own merits, and see the light as distinguished from the shadow.

C. L. de Muralt: Mr. Townley made a certain *reductio ad absurdum* when he showed that, if you can use a single power station to supply one town, there is no reason why you should not use it to supply one county, or one state, or finally you might as well supply all of the United States from one single power station in Chicago. That, of course, would be absurd, but I think it is not quite fair to Mr. Insull to consider his paper in just this manner. I do not think Mr. Insull had any such thing in mind, but I can easily conceive of his having in mind the supplying of all of the United States from one single network of lines, controlled by one company, which owns all sorts of power stations in the most convenient places, steam, hydraulic, etc., and I do not doubt for one moment that the country would benefit by such a combination, provided it could be properly regulated. The figures which Mr. Stott has given show plainly how such a combination of various loads will decrease the operating expenses proper, and then there is the still greater gain in the saving of fixed charges on equipment which can be eliminated if the load factor is high.

On this point it seems to me worth while to call attention to some information contained in Mr. Insull's curves but not specifically mentioned by him. I will first refer to Fig. 4, which represents the power requirements of the railroads electrified in the district of New York, the Pennsylvania Railroad, the New York Central & Hudson River Railroad and the New York, New Haven & Hartford Railroad. You will notice that each one has a strong peak at about eight o'clock in the morning and another strong peak at about six o'clock in the evening, and a very deep valley between. Incidentally you will notice that the peak and the valley are much less in the curve of the New Haven than they are in the curves of the Pennsylvania and the New York Central, which seems to contradict Mr. Murray's claim that his company has the worst load factor.

What I wish to bring out, however, is that the two peaks of this kind of railroad service practically coincide with the customary peaks in the lighting and power business, which also occur roughly at from six to eight o'clock in the morning and from six to seven o'clock in the evening. In other words, superimposing this sort of a railroad load on the usual power and lighting load will not help very much, which may explain why Mr. Insull is disappointed in the saving which he can make by improving the diversity factor in this manner. It is necessary to remember that these are all strictly suburban train services. The New York Central, the Pennsylvania and the present New Haven installations run essentially suburban passenger trains.

Now let us refer to Fig. 8. You will see at once the difference between the passenger curve and the freight curve. The passenger curve in this case also represents a suburban passenger train service. It stands for the Chicago terminal operation, and it has two very plain peaks, but the freight curve is a very much smoother curve—as a matter of fact, it is practically at its maximum value just during the time when the other curve has its deepest valleys. Thus, while the total is not by any means a horizontal line, the difference between its lowest point and its peak is very much less than in the case of the passenger curve.

The conclusion which I should like to put before you is this: The electrification of our railway terminals alone is not going to help us very much, but the further out we go, and the more we include freight business and through passenger trains, the more will we be able to smooth out the load curve. This is perhaps the strongest argument which Mr. Insull has brought out in his paper in favor of consolidation over as large a district as possible. We need not necessarily consider a single power house in one city, but let one company furnish, by means of a series of power houses and a network of lines, the electric energy required for all purposes, light, power and traction, in a large territory and the cost of electricity to everybody concerned is bound to be reduced.

N. W. Storer: Apparently all of those who have discussed Mr. Insull's paper are agreed on certain things. Certainly no one

can refuse to admit that, from an economic standpoint, it would be better if all of the power used in any community were generated and distributed by one organization, provided that organization was so managed as to give the service desired by power users. Looking at it broadly, without any reference to organization, if every power user were able to get as much power as he desired at any time and in any place by connecting to a power distribution system, he would be relieved of all responsibility of a power house and everything connected with it. Under such conditions a great many projects would be financed, that are now impossible. It should be possible, as Mr. Insull states, for power to be distributed in this way and sold at a lower cost than it would be possible for the individual users to generate it. This statement, I believe, will be admitted by all.

When it comes to the organization of the distributing system, of course it would naturally follow that generating stations should be of the most economical size, and should be so interconnected as to get the best and most economical distribution system. It might be most economical to have one organization to distribute power to the entire country. This, of course, is not a possibility at the present time, neither is the single distributing company in large cities a possibility, for the reason that no large railway corporation or other large user of power is going to put this work in the hands of any company which may be controlled by rival capitalists. If there were no fears on the part of power users that they were putting their business in jeopardy by permitting all power to be concentrated by one company, there is not a particle of doubt in my mind that concentration would be made in the near future. There are too many cases in view at the present time, where communities are at the mercy of a single corporation, being obliged to pay exorbitant rates for their power, to encourage people to extend this system any further. The ideal system which Mr. Insull advocates can be put into effect only when the power companies are put under the control and the prices are subject to the regulation of an honest and efficient government. The question then, resolves itself into one of politics rather than engineering.

Now, as far as the railway load itself is concerned, it has been pretty clearly demonstrated that the railway load will have the best load factor of any of them. The passenger system alone has very bad peaks in its loads, but when a freight load is superimposed on the passenger load, such as will be the case in any large city where there is a great deal of shifting and freight handling going on all the time, an exceptionally good load factor is obtained. From this standpoint, then, there would be little advantage to the railroad in buying power from a central company. Railroad companies can generate their own power, but, of course, one railway company will not be able to sell power to a rival railway company. If a number of railways are to be operated by power from a single power system, this system must be under joint control of all the companies concerned, or

controlled by a company which is absolutely independent of any of the others, and is bound to treat all companies alike.

In further consideration of the application of this paper to steam railway electrification, I do not feel that it is going to be necessary for the railway companies to use absolutely the same system of distribution as is in use in the majority of the central stations in any given locality. It certainly would be advantageous if railways could use this same system, but the railway load is big enough and the load factor is good enough to give the most economical production of power, and if the railway companies found it more economical to adopt a different system of distribution than the one in use locally, they would be entirely justified in changing. That, of course, simply means that if they wished to do so, they could adopt a different frequency—in other words, if 15-cycle alternating current with either single-phase or three-phase distribution to railways were found in the long run to be the best suited for their operation, they could be perfectly free to adopt that frequency regardless of the frequency in use by other central stations. I do not wish to be understood as stating, or necessarily believing, that 15-cycle current is going to be the one adopted for the electrification of steam railways. My statement is not intended to have any meaning between the lines. The frequency of 15 cycles is given simply as an example.

Edward N. Lake: Concerning the Boston Elevated Railway Company's new power station, about which Mr. Insull had something to say, I wish that I were at liberty to give some figures on this question, but perhaps all that need be said, now, is that considering the rate which I understand was offered by the Edison Company, and the actual cost now being secured by the new station of the Boston Elevated Railway Company, the directors of the latter company have had no reason to question the wisdom of their decision to build their own power station.

Frank J. Sprague: We have in use three systems of electrification of steam railroads, somewhat distinctive: polyphase, single-phase and direct-current, and some combinations of two or more of these. I am somewhat of an agnostic, but I have directed my energies for some years past not only to promoting electric railway operation, but to trying to see that efforts should be consistently carried forward in each of these fields to arrive at the normal maximum development of the apparatus which goes to make up the constituent part of each of these systems. We have arrived at a reasonable degree of satisfactory operation so far as central station equipment and apparatus is concerned; we have gone nearly as far as we can hope to go in the matter of reliability, in the matter of efficiency and in the matter of producing units of economical size. We have arrived at certain general conclusions as to the operation of central stations. We have also learned the necessity of permanence of construction, when we deal with steam lines which have been electrified—where we are tending all the while to more exclusive

rights-of-way, where highways shall not cross railroads at the same level. We are also introducing, from time to time, important improvements in the matter of physical construction. We are adopting certain standards in the interests of our great cities, and our public service commissions are placing more and more restrictive obligations upon those who supply electricity for use within crowded areas.

In the matter of line construction, whether for transmission or for carrying the overhead wires over a railway, or the construction for protected or unprotected third rails along the right-of-way, we have arrived at fairly definite conclusions, and fairly good experience in the matter of cost. In the matter of motors there have been very great advances made in the past three years, so that I think we can look forward with reasonable assurance to certain normal limits to the potentials which are practically available for each of these systems. I do not mean that higher potentials are not workable, but there are limiting features which come up which go to make up a balance which we must regard.

In polyphase work we should not go above 6000 volts between adjacent trolley lines, because when we go above that we do not gain enough in the matter of economy of transmission to pay for the extra cost of maintaining these wires at this excess of difference of potential. For single-phase lines I doubt if we will achieve anything of importance by increasing the potential much above 11,000 to 12,000 volts, possibly sometimes to 15,000 volts. In direct-current work the old standard of 600 volts has disappeared, and my impression is that where overhead lines are used there is a practical, normal limit, all things considered, of say from 2500 to 3000 volts. Where protected third rails are used, there is a normal limitation of from 1200 to 1500 volts.

So far as the motors themselves are concerned, we have got pretty nearly to the limit of capacity measured by weight, with and without ventilation, natural in the motor or supplied from an extraneous source.

Now having arrived practically at these limitations, I say that the time is fast approaching when, as engineers—divesting ourselves of any particular pet notions, so far as it lies in our power, and not abating in any sense the right to make individual efforts along the lines of progress for which we are responsible—we should pave the way to get comparative results which will enable us to arrive at proper conclusions in the future. In and around New York we have the New York Central, the premier system so far as that particular class of work is concerned, and we have the New Haven System, one of these operating to North White Plains and Yonkers, and in the future going on also to Croton and possibly to Poughkeepsie, and the other operating at the present time to Stamford, and later going on to New Haven, and perhaps further points. Each performs a service which is adequate so far as the hauling of trains is concerned, but one which is disappointing in some ways so far as

the total economic results are concerned, for in each case the railroad is, for the present, handicapped by having to operate in the same zone with steam equipment, and also because all the wheels of those divisions are not turned electrically, as I have, for the past seven years, urged should be done.

A sub-committee of the Railway Committee has been charged with the duty of suggesting methods for promoting the use of uniform reports by the steam railways which have been electrified, covering the electrified divisions. I think it is the duty of all electrical engineers to promote, as far as lies in their power, these uniform reports. The five or six railway central stations have already framed up these for their individual comparisons, but I think probably we would get a little further along than we have done if these reports would also deal with the general equipment, and specifically with the cost of operation. The latter will not always show up well for any one of these systems, and in other respects it will show up very well. Now, when a single-phase system, or a direct-current system, or a polyphase system, is extended over an area sufficient to eliminate the steam engine within the zone of operation, and when those who are in executive control and in responsible charge are willing to lay down in a comparative manner all the facts about their equipment and operation, I think that the electrical engineers of this Institute will have that to which they are entitled, and which eventually they must have before they can come to any final conclusions, irrespective of my own or any other man's impressions, as to what should be done in the future. So far as lies in my power as a member of this Institute, that is precisely the thing I am going to work for—to get the facts, no matter what they are, about any and all systems, so that we can all pass proper judgment and arrive at correct conclusions.

I cannot agree with some of the conclusions expressed in the paper, because I have not sufficient data, but there is underlying all this discussion one fundamental fact. Everyone is agreed that we should have consolidation of power houses sufficiently large and well enough equipped to insure reliability and safety in operation and economy of operation. Within a given area a station should be capable of supplying all the energy required in that area, and two or more of these stations can properly be connected together for the supplying of larger areas; in other words, we can extend the high-tension busbar over large areas, and where there is a common territory between two stations either can be utilized to relieve otherwise unbalanced overloads.

I am in hopes of being instrumental in trying to bring about the state of affairs which Mr. Sothman happily voiced, that where two or more people who have all of the facts, and have that one quality which is the highest quality engineers can have, and which all engineers should possess to a greater or less degree, the power to analyze, these men cannot help arriving at a unity of judgment provided they are fair-minded in their engineering notions.

A paper presented at the Baltimore Section Meeting of the American Institute of Electrical Engineers, Baltimore, Md., April 9, 1912.

A VISIT TO THE PANAMA CANAL.

BY E. D. EDMONSTON

I was fortunate in being able to make the Panama trip as one of the A. I. E. E. party which sailed from New York last January 17th, joining the New Orleans contingent upon our arrival at Colon January 25th. Here we were greeted by the receiving party composed of Colonel Seibert, a member of the Canal Commission and in charge of the Atlantic Division of the work, Mr. Schildhauer, the electrical and mechanical engineer of the Commission, and Messrs. Cornish and Kratz, engineers of the Canal Commission.

During our seven days stay on the isthmus we made daily trips from Panama city in a special train, attended by one of the Canal Commissioners and a corps of the engineers having charge of the particular division of the work to be seen on that day; and thus our party was given most unusual opportunity to inspect the canal work at close range.

I am going to take you over the canal as we saw it, step by step from the Atlantic to the Pacific, explaining as we go, some of the main features of the great work being accomplished by American money, brains and energy, in the uniting of the two oceans, which work is now nearing completion.

First, let us review our geography and get clearly in mind the relative location of the isthmus, and why a canal through it is desired.

Distance from San Francisco to Panama	3269 nautical miles	nautical mile =
" " New York " Colon	1980 " "	6086 ft. = 1.85 km.
" " " " to San Francisco via Strait of Magellan	13090 miles	
" " " " " " " " Panama	5299 "	
Saving	7791 "	

Distance from New York to Honolulu via Strait of Magellan	13269 miles
" " " " " " " Panama	6687 "
Saving	6562 "
Distance from New York to Manilla, P. I. via Suez	11644 "
" " " " " " " " Panama	11379 "
Saving	265 "
Distance from New York to Yokohama via Suez	13040 "
" " " " " " " Panama	9835 "
Saving	3205 "
Distance from New York to Hong Kong via Suez	11460 "
" " " " " " " " Panama	11415 "
Saving	45 "
Distance from New York to Sidney, Australia via Str. of Magellan	12546 "
" " " " " " " " Panama	9814 "
Saving	2732 "

Though great as is the saving to be effected in distance of travel between certain shipping points, by a canal across the isthmus, the expenditure of $375,000,000 the estimated cost to construct the Panama canal, can hardly be considered in the light of a paying business proposition for this country, for the commercial shipping of this country has never, so far, justified the building of the canal. Our own merchant marine, almost a minus quantity at present, is a joke among seamen; but let us hope that the shortening, by the canal, of water travel between our Pacific seaboard and Atlantic and Gulf ports, will offer that incentive necessary to create an American merchant marine.

The traffic through the Panama canal, for some years to come, will probably be much less than through the Suez canal; and the total tonnage through the Suez canal for the year 1909 was 15,500,000 tons.* Therefore, assuming that the marine of all nations uses the Panama Canal whenever distances of travel can be shortened, and a maximum toll which such traffic can stand is collected, it would appear as though it will be many a day before the tolls from the canal will pay anything like a fair interest on the money invested, aside from the cost of maintaining and operating the canal. The latter costs, it is thought, will be comparatively small.

But, the construction of the canal was not undertaken by this country as a money-making proposition—the long trip of the battle-ship Oregon around the Horn from Pacific to Atlantic at the outbreak of the Spanish-American War in 1898, determined

*One ton = 0.9 metric ton.

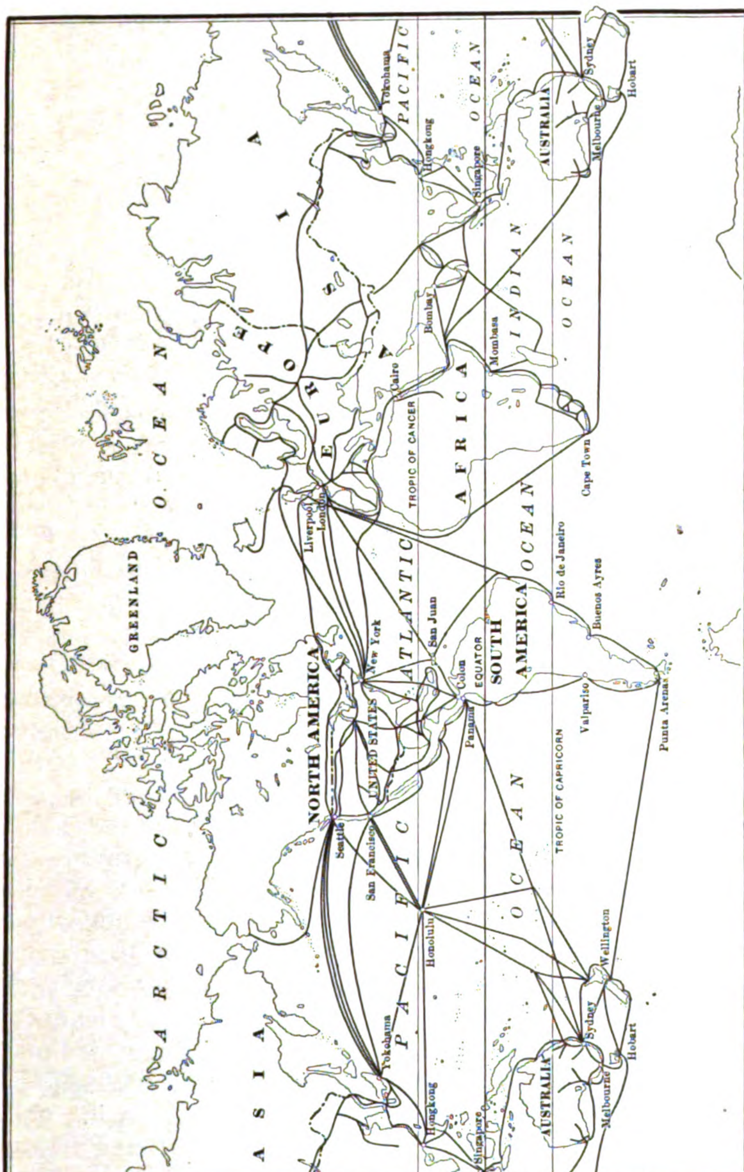


FIG. 1—WORLD MAP SHOWING TRANSPORTATION LINES.

the advisability of this country constructing an isthmian canal. Many will remember the anxiety in this country for the safety of the Oregon during that long journey to join Sampson's fleet; and as a means of concentrating our war vessels in time of war or threatened war, without taking that long, tedious, and uncertain route around the Horn, this country thought an expenditure of $375,000,000 for the canal well worth while; and therefore commerce should not rightly be expected to bear a large portion of the canal debt, but that debt should be charged to the account which necessitated its construction.

After the United States determined that a canal across the isthmus was necessary for the best interests of this country, two routes were considered; the Nicaraguan route, and the Panama route. The latter route determined upon, the President of the United States, by the Spooner act, approved June 28th, 1902, secured the necessary concessions from the Republic of Panama, purchased the rights and property of the New French Canal Company, and began on May 4th, 1904, the great work of constructing the Panama canal, a work in which the French had failed.

The canal which the Spooner act authorized the President to construct, was the lock type as recommended by the first Isthmian Canal Commission in its report submitted in November 1901, and notwithstanding the repeated storms of protest which swept the country in favor of a sea-level canal, and reports of eminent engineers in favor of the latter type, the recommendations of the first Commission for a lock canal held good. As the work is nearing completion, and the ultimate success of the project is no longer a question of doubt, the wisdom of the choice of lock type canal is very generally acknowledged, especially by engineers who have thoroughly inspected the work on the Isthmus. And this because of the infinitely greater difficulties which would have been encountered on account of the nature and lay of the land, in attempting to construct a sea-level canal with its consequent much greater cost, and the greater time required to complete. The French, in their unfortunate attempts to build a Panama canal, began their work about 1880; and the type of canal which they had determined upon was a lock canal. The French had done much work of great value, and the United States paid the French company $40,000,000 for its franchises, work done, property, material and equipment; which our Canal Commission now estimates was worth about $42,800,000 to this country.

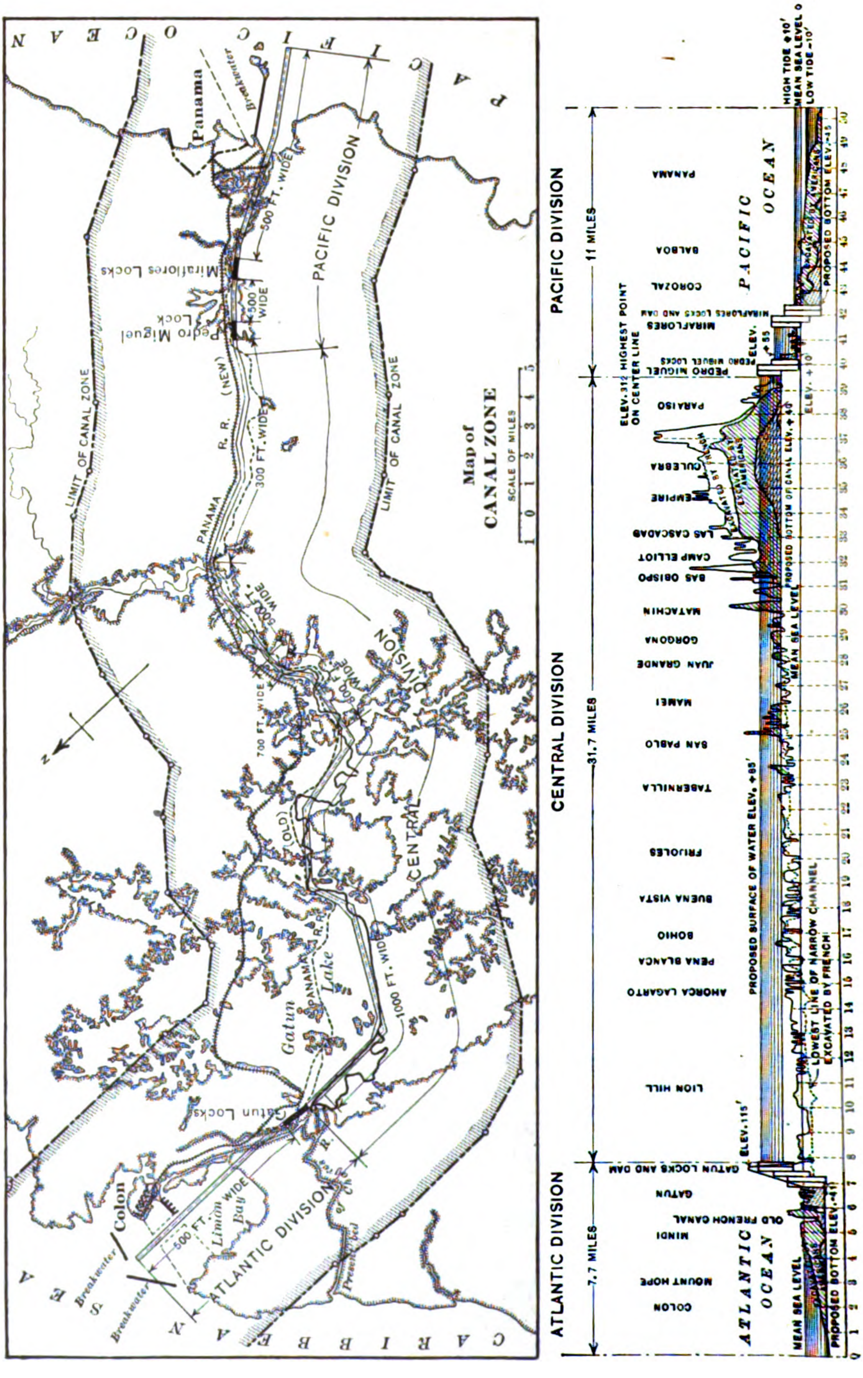
It may be seen from the map of the Canal Zone, Fig. 2, that the Isthmus of Panama runs nearly east and west, and the canal traverses it from Colon on the north to Panama on the south, in a general direction from northwest to southeast, the Pacific end being 22 miles (35.4 km.) east of the Atlantic entrance.

The Canal Zone is 10 miles (16 km.) wide; 5 miles (8 km.) on each side of the center line of the canal, and contains about 448 sq. mi. (1150 sq. km.) The United States owns this entire zone with the exception of the cities of Colon and Panama which are excluded, but within which this country has the right to enforce sanitary ordinances and maintain public order.

The popular conception of the canal seems to be that it is a long straight ditch of uniform width; and many think that it is walled with concrete, but as a matter of fact it is a tortuous channel, of varying widths, walled by the natural earth or rock, and comparatively little concrete has been used, aside from that in the locks and portions of the dams.

The total length of the canal, from deep water on the Altantic side to deepwater in the Pacific is about 50 miles (80 km.) and from shore line to shore line about 41 miles (65.9 km.)

Entering the canal from the Atlantic side is a 7-mile (11.2 km.) sea-level channel through Limon bay and the mainland to Gatun which will have a bottom width of 500 ft. (152.4 m.), and a depth at mean tide of 41 ft. (12.5 m.) At Gatun an 85-ft. (136.7-m.) lake level will be obtained by a dam across the valley. This map shows the water in the lake as it will be when the Canal is completed. The lake thus formed will have an area of 164 sq. mi. (424 sq. km.) and will be confined on the Pacific side by a dam between the hills at Pedro Miguel 32 miles (51.4 km.) away. The channel depth throughout the 85-ft (25.9-m.) level will be not less than 45 ft. (13.7 m.) at normal stage. The width of this channel from Gatun to Pedro Miguel, is 1000 ft. (304.8 m.) in the main portion of the lake, then decreases to 800 ft., 700 ft. and 500 ft. (243.8 m., 213.3 m. and 152.4 m.) to Bas Obispo the Atlantic side of Culebra cut; and the bottom width of the cut to Pedro Miguel will be 300 ft. (91.4 m.) stepping down there through the Pedro Miguel lock to a small lake held at 55 ft. (16.7 m.) above sea level by a dam at Miraflores. There will be a channel of 500 ft. (152.4 m.) bottom width and 45 ft. (13.7 m.) depth for a distance of about 1.5 miles (2.4 km.) to Miraflores locks; thence again stepping down to sea-level, and out through a channel 45 ft. (13.7 m.) deep at mean tide, with a bottom width



FIGS. 2 AND 2.—MAP OF CANAL ZONE AND PROFILE OF CANAL.

of 500 ft. (152.4 m.) for a distance of 8.5 miles (13.6 km.) through the mainland and Panama Bay to deepwater in the Pacific.

The location of breakwaters on the Atlantic and on the Pacific sides should be noted, as well as a small group of islands in the Pacific, some of which will be fortified by this country, to protect the canal in time of war. The breakwater on the Atlantic side is needed to protect vessels in Colon harbor from the very violent storms which occasionally come from the Caribbean Sea, and to make the entrance and exit of ships from the canal during such storms. The Atlantic breakwater stands out about two miles (3.2 km.) from Toro Point. The Pacific entrance requires no protection from storms, but the breakwater is needed to prevent the channel from quickly filling with silt which otherwise would be carried in by the current and make constant dredging necessary to keep a clear channel depth. The length of this breakwater from Balboa to Noas island is about 3.5 miles (5.6 km.).

I would also have you note the location of the Atlantic channel of the old French canal, which channel has been abandoned.

The present bed of the Chagres river, as well as the location of the original Panama R. R., and the new re-located line are shown. The old Panama railroad goes through what will be the lake, at an elevation below what will be the lake level, and therefore it was necessary to build a new portion of line above what will be the lake level, and to locate it on higher ground.

The horizontal scale of the profile map, Fig. 3, is 100 times greater than the vertical scale.

A steamship in passing through from the Atlantic to the Pacific will enter the approach channel in Limon bay under its own steam, travel to Gatun where it will enter a series of three locks in flight and be lifted 85 ft. (25.9 m.) to Gatun lake, being hauled through the locks by electric locomotives. From Gatun it may steam at full speed through the lake to Bas Obispo for a distance of about 24 miles (38.6 km.) where it will enter Culebra cut. Thence through the cut to Pedro Miguel lock, where it will be entered by electric locomotives, and then lowered 30⅓ ft. (9.24 m.), by one step to Miraflores lake. Steaming through the 1.5 miles (2.4 km.) of lake to Miraflores locks, electric locomotives will again take it in tow through the locks, where it will be lowered 54⅔ ft. (16.6 m.) through two locks in series, to sea level in the Pacific, steaming away from this point into the Pacific ocean. If the vessel happens to be a sailing ship, it will be conveyed through the canal by canal tugs.

The total variation in tides on the Atlantic side is 2.5 ft. (0.75 m.) as a maximum, and on the Pacific side it is 21.1 ft. (6.4 m.) as a maximum.

The Department of Construction and Engineering is divided into three construction divisions; the Atlantic Division embodying the construction from deep-water in the Caribbean sea, to and including Gatun locks and dam; the Central Division extending from Gatun to Pedro Miguel and having in charge the Culebra cut; and the Pacific Division covering all work on the Pacific side of Pedro Miguel, including the locks and dams of Pedro Miguel and Miraflores.

At Cristobal work is being done in Colon Harbor to provide an extensive system of docks, Fig. 4, where ships may tie up and transfer freight.

Proceeding to Gatun, Fig. 5 gives some idea of the nature of the locks. This illustration of one side of Gatun Locks, looking towards the Atlantic, shows the three flights in locks, and you will notice at the far end they have begun to erect one of the lock gates.

In the general plan and profile of the locks showing the lock gates, Fig. 6, you will notice that all of the locks are in pairs, so that if any lock is out of service, navigation will not be interrupted; and when all of the locks are in use, passage of shipping will be expedited by using one side of locks for the ascent and the other side for the descent. Each of the locks is 110 ft. (33.5 m.) wide and has a usable length of 1000 ft. (304.8 m.). The depth of locks from top of walls to bottom of chambers is approximately 79 ft. (24 m.) except in the lower flight of Miraflores Locks where the depth is slightly increased on account of the great variation in tides in the Pacific.

Each lock will be a chamber with walls and floors of concrete and mitering gates at each end. There is a double pair of gates at each end of each of the locks, and at one end of Pedro Miguel lock is an additional pair of guard gates. This double gating is for the sake of safety; to permit of repairs being made to one pair of gates, while the other pair is made use of, and to give added insurance against some mishap which might otherwise put one side of the lock out of commission. The intermediate gates are placed in the lock chambers to save both time and water in passing vessels of under 600 ft. (182.8 m.) in length. These intermediate gates divide the locks into chambers 600 ft. and 400 ft. (182.8 m.) long respectively. More than 95 per cent of the

FIG. 4—SHIP SLIPS UNDER CONSTRUCTION AT CRISTOBAL. [EDMONSTON]

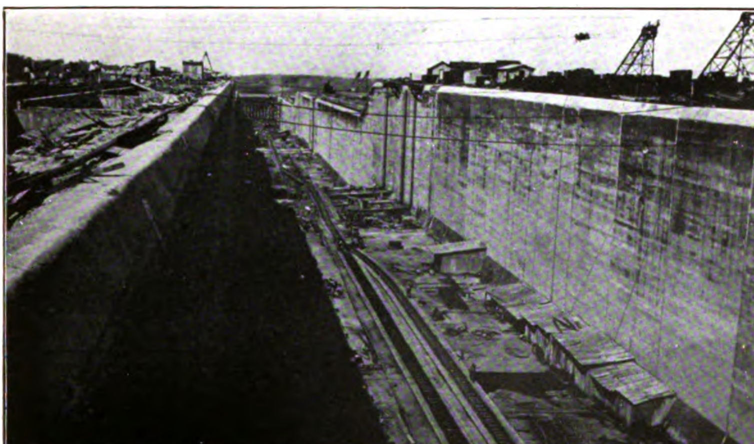


FIG. 5—ONE SIDE OF GATUN LOCKS, VIEWED FROM ABOVE. [EDMONSTON]

FIG. 7—GATES UNDER COURSE OF CONSTRUCTION. [EDMONSTON]

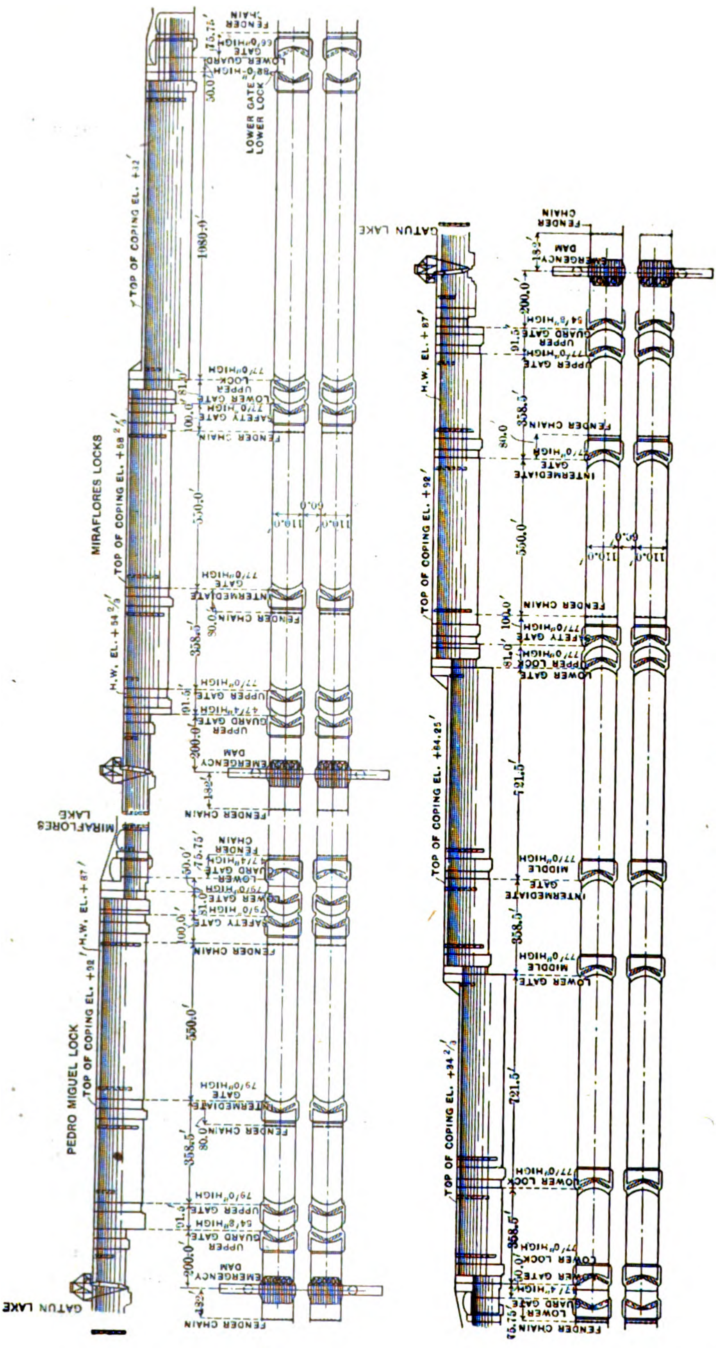


FIG. 6—GENERAL PLAN AND PROFILE OF ALL LOCKS.

vessels on the high seas are less than 600 ft. (182.8 m.), in length, so these intermediate gates will be very frequently used.

To protect the gates against vessels crashing into them, fender chains are stretched across the lock walls, the locations of which may be seen, which chains are so controlled as to be capable of checking a ship of 10,000 tons capacity moving at the rate of five miles (8 km.) an hour, within 70 ft. (21.3 m.) or before the ship could reach the nearest gates.

As an additional precaution to cope with accidents which may happen, emergency dams are provided at the head of each flight of locks, consisting of swinging bridges which can be thrown across the locks in case of an accident to nearby gates. The location of these emergency dams is shown, and I will later go more into the details of them.

The lock gates are steel structures of a maximum thickness of 7ft. (2.1 m.), 65 ft. (19.8 m.) long and from 47 to 82 ft. (14.3 to 24.9 m.) high.

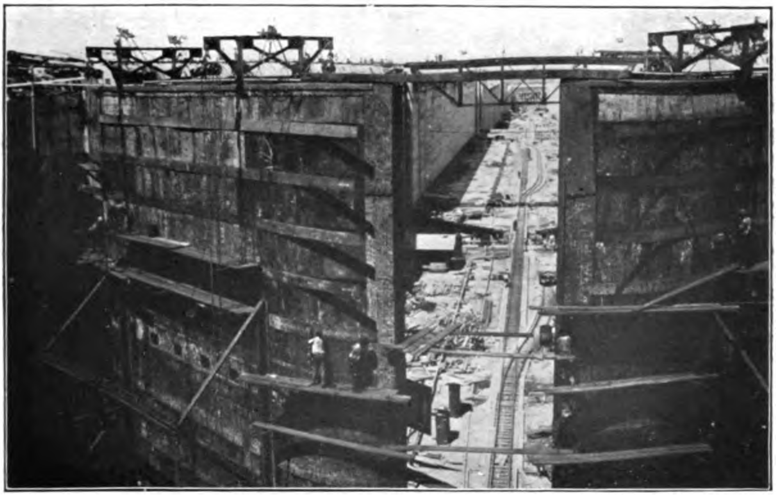
As all the lock gates are of the same general design, the illustration, Fig. 7, of a pair of lock gates, which happened to be in Pedro Miguel lock, will give an idea of the structural steel frame work of the gates. This frame work is to be covered by steel plates securely riveted to it.

Fig. 8 shows a pair of gates nearing completion, and the method of applying the plates.

Fig. 9, taken a few hundred feet nearer the Pacific end, shows the double pair of gates and a view down into one side of Gatun locks.

There are 92 leaves or single gates required for the entire canal, and each of these leaves, or single gates, weighs from 300 to 600 tons. In each gate there is an air chamber formed at the bottom by the plates, which air chamber when the water is turned in, will buoy up the great mass of metal. Later is shown the details of the machinery for swinging the gates, and the provisions for making the gates tight.

The side walls of all locks are 45 to 50 ft. (13.7 to 15.2 m.) wide at the floor level; are perpendicular in race, except for the slight battering near the floor surface; and narrow by stepping off from a point 24⅓ ft. (7.4 m.) above the floor, until they are 8 ft. (2.4 m.) wide at the top. The middle wall of all locks is 60 ft. (18.2 m.) wide, with vertical faces. The middle wall at a point 42⅓ ft. (12.9 m.) above the surface of the floor, divides into two portions leaving a space in the center which is tunneled over.



[EDMONSTON]

FIG. 8—GATUN LOCKS AND GATES NEAR PACIFIC END, LOOKING TOWARDS ATLANTIC.

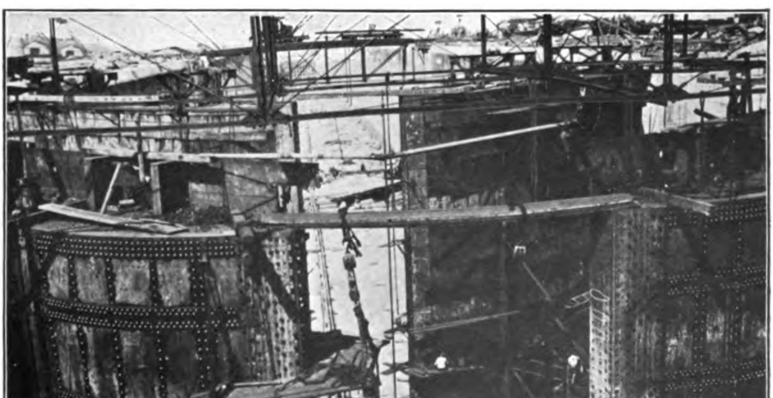


FIG. 9—GATUN LOCK AND DOUBLE GATES. [EDMONSTON]

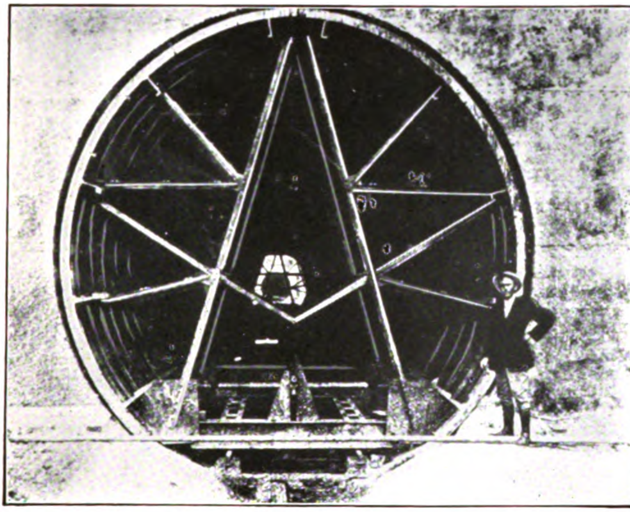


FIG. 11—EIGHTEEN FOOT CULVERT. [EDMONSTON]

[EDMONSTON]

FIG. 12—ONE SIDE OF GATUN LOCKS, NEAR CENTER, LOOKING TOWARDS PACIFIC.

In this space operating machinery is placed for moving gates, controlling valves, etc. In this space is also provided passageway for operators; conduits for electric wires, and a drainage passage.

The locks will be filled and emptied through a system of culverts, one of which is shown in Fig. 10, in each of the side walls and in the middle wall. The area of each of these culverts is approximately 254 sq. ft. (23 sq. m.) about the area of the Pennsylvania Railroad Hudson river tunnels, and these culverts extend the entire length of the lock walls. From these main culverts are the lateral culverts, at right angles to the axis of the lock, from which are openings upward into the lock chamber. The locks will be filled and emptied through these many openings in the floor, thus distributing water as evenly as possible over the entire horizontal area of the lock, and reducing the disturbance in the chamber when the latter is being filled or emptied. The lateral

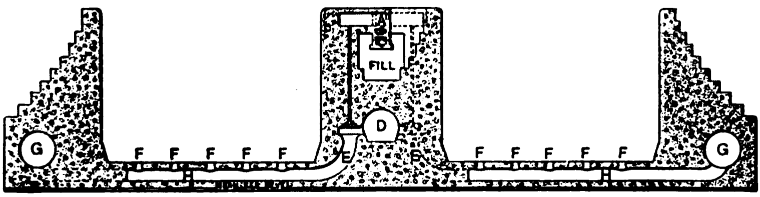


FIG. 10—TYPICAL CROSS SECTION THROUGH LOCKS.

culverts are spaced about 36 ft. (10.9 m.) apart, leading alternately from the side and middle main culverts. Valves which may be opened or closed either individually or all at one time will be located at the intakes and outlets of the main culverts, and at the connections between the center culverts and the lateral culverts. In the cut you will notice the valve at the junction of the center main culvert and a lateral culvert, which valves are balanced cylindrical valves operated by electric motors. The locks can be filled or emptied in about eight minutes.

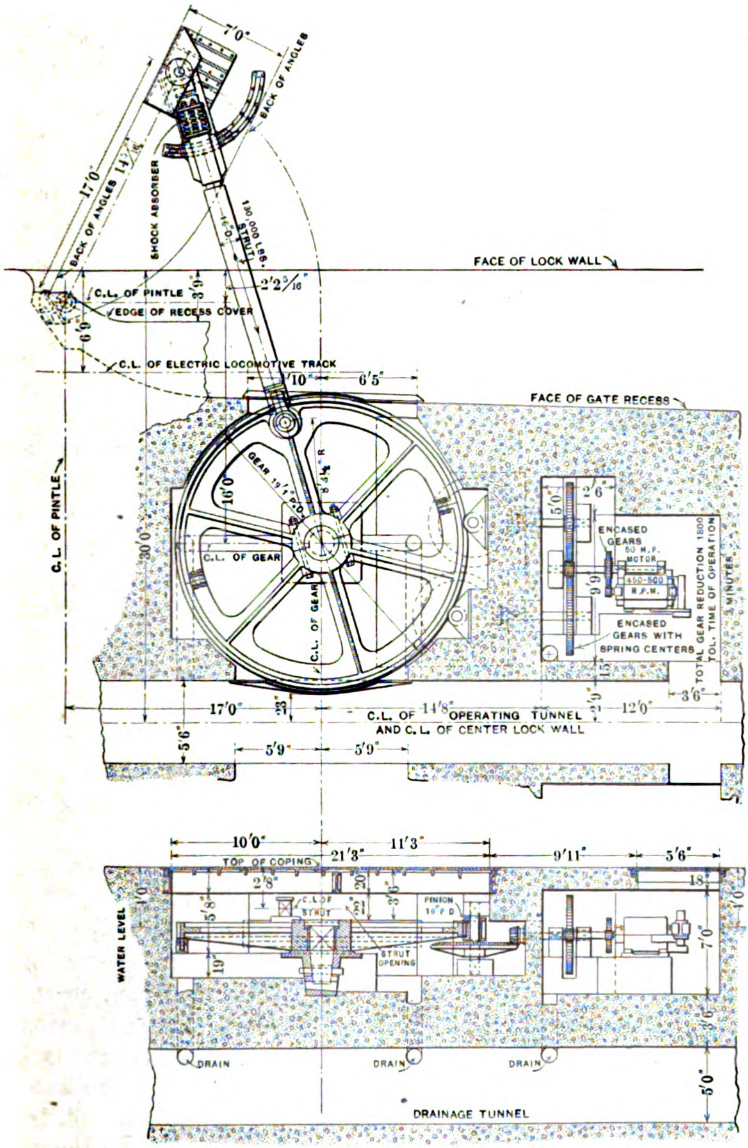
Fig. 11, shows one of the main side culverts with the collapsible steel centering. This steel centering, mounted on trucks, was moved along as the concrete work on the lock walls was done.

A view from a point down in one side of Gatun Locks, looking towards the Pacific end, Fig. 12, shows the inclines on the top of the lock walls at each flight, which electric locomotives will climb in towing vessels through the locks.

From Fig. 13, showing, in plan and section, the operating mechanism for opening and closing the lock gates, it will be noted that motion is imparted to the gate leaf by a rigid horizontal strut, connected by a vertical pin to the upper girder of the gate leaf. The other end of the strut is fitted to a crank pin attached to a large horizontal gear wheel near its circumference. The gear wheel is made to turn by a pinion or pinions revolving on a vertical axis, and actuated by a 50-h.p. motor through a suitable train of gears. The gate leaves are of so great a size that unusual care has to be exercised to regulate the force applied to the leaf in a manner approximately proportional to the resistance to its motion, and this design complies with the requirement.

Gate valves control the water in the main culverts for emptying and filling the locks. The mechanism consists of a single rising valve stem with the lower end connected to the valve gate. This stem passes through a stuffing-box in a water-tight bulkhead, which bulkhead seals the bottom of the machinery chamber 32 ft. below the high level of the water in the lock. The upper end of the valve stem is carried by a crosshead actuated by two vertical, revolving, non-rising screws, driven by a 50-h. p., three phase, 25-cycle, 220-volt induction motor through a friction clutch and reducing gear. The motor is arranged for either local or remote control, and auxilliary hand apparatus is also provided for closing the gate should it ever be necessary to do so without using the motor. The crosshead which lifts the valve stem, actuates also a train of live rollers to which the valve when in action transmits the pressure of the water, and on which it rolls when lifted. These roller trains must rise with the gate and at half its speed.

Chain fenders, as mentioned, protect the lock gates against damage by ships. The fender consists of a heavy chain stretched across the lock near the surface of the water and arranged to pay out against a resistance when struck by a vessel, so as to gradually stop the latter without injury. The chain is lowered to the bottom of the lock when a vessel is about to pass the gates it protects. The mechanism for raising and lowering the chain, and offering resistance to the pull of the chain, consists of a system of hydraulic cylinders operated by a motor-driven centrifugal pump. There is, at the top, a stationary outer cylinder bored out at its lower end to receive a moving combination plunger cylinder; which in turn has its lower end bored out for



SECTIONAL ELEVATION

FIG. 13—OPERATING MACHINERY FOR LOCK GATES.

a stationary hollow plunger which is anchored to the bottom of the pit. The intermediate cylinder carries two sheaves over which the chain passes. The intermediate cylinder is moved vertically by introducing water through the pipe leading to the top of the outer cylinder for downward movement, or through pipe leading to the bottom of the stationary plunger for upward movement which lowers the chain. The resistance to the paying out of the chain is provided by emergency resistance valves. When the chain is struck by a ship, the water pressure in the large outer cylinder rises gradually, the resistance valve being so designed that when a pressure of about 750 lb. (340 kg.) per sq. in. is reached the valve will open and allow a sufficient amount of water to escape to keep this pressure constant until the vessel is stopped. This pressure of 750 lb. (340 kg.) corresponds to a stress of 100 gross tons (101.6 metric tons) on the chain.

The emergency dam consists of a structural bridge pivoted on a side wall of the lock. The length of this bridge normally lies parallel with the axis of the lock, but when there is need to dam the lock opening the bridge is revolved by two-110-h.p. motors until it spans the lock channel. Then wicket girders are lowered, by motors, from the bridge to pockets in the bottom of the lock channel, and rolling gates run down on these girders, which gates dam off the lock.

In addition to the emergency dams, for daming off the water in the locks, floating caisson gates will be provided to close off the head and tail bays of the lock flights. Each of these caissons is to be equipped with motor-driven centrifugal pumps for pumping out the caisson and unwatering the locks. These caissons will be floated into the locks when needed, and placed in position across the locks against barriers on the lock walls, and against a sill provided on the bottom of the lock chamber.

It has been stated that no ships may pass through any of the locks under their own steam because of danger of damaging the ship or lock gates. A ship will come to a full stop between the approach walls of one flight of locks, where four electric towing locomotives (Fig. 14) operating on the lock walls will make fast to the ship by means of hawsers. These hawsers on the locomotives pass over windlasses. Two of the locomotives will be forward towing the ship, and two aft being towed by their hawsers and thus holding the ship steady. The ship will thus be between four taut lines of hawsers, and will be passed through the locks at the rate of two miles (3.2 km.) an hour. The locomotives

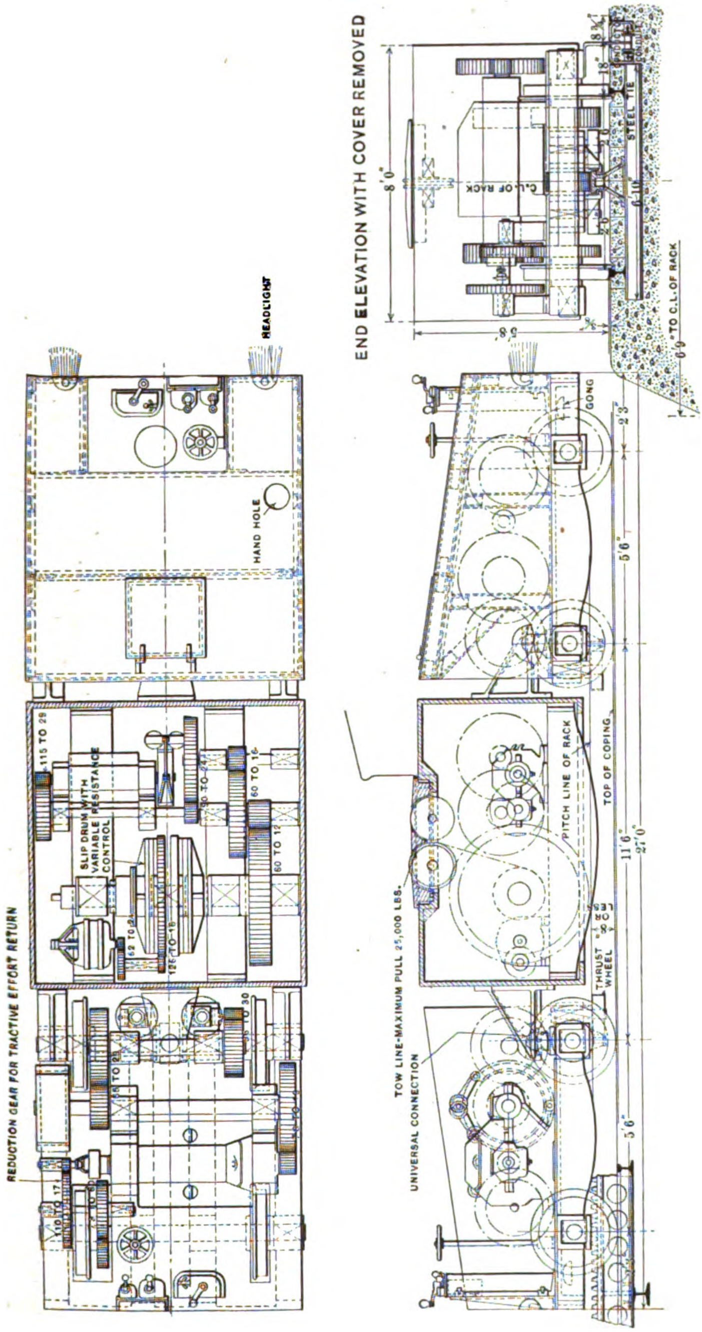


FIG. 14—ELECTRIC TOWING LOCOMOTIVES

will remain with the ship until the vessel is delivered clear of the locks and between the opposite approach walls.

Locomotives will run on a level, except where they pass from one lock to another, when they are called upon to climb very heavy grades, the maximum grade being one in two.

There will be two systems of tracks, one for towing and the other for the return of the locomotive when not towing. The towing track will have a center rack throughout, and the locomotives while towing will always operate on this rack. On the center wall there will be two towing tracks with one return track between them, and on each side wall a towing and a return track.

Each locomotive will consist of three parts; two tractors alike in every particular, and a windlass section. The windlass section is not mounted on a truck, but is supported by two arms extending on each side and resting on bearings immediately over the adjacent wheels of the tractors; and it is joined to the tractors by a draw bar and trunnion which will have the effect of a universal joint.

The motors are of the high torque induction type, three-phase, 25-cycle, 220-volt, and totally inclosed. The motors on the tractors of each locomotive will be operated in parallel and controlled by resistance in the secondary circuit. They will be controlled by master controllers in the cabs at either end. Current will be supplied to the locomotives by means of a plow carrying two contact shoes each operating on a separate contact rail in an open conduit as shown, for each of two phases, while the third phase will be carried by both track rails. The tractor motors are of 75-h. p. each.

The windlass is driven by two motors of 7½-h.p. and 2-h.p., the first for operating the windlass under load, and the smaller for the rapid coiling of the hawser. There will be 40 of these locomotives required for all of the locks.

For the concrete work at Gatun, Fig. 15, crushed rock is obtained from the quarries and crusher at Porto Bello about 20 miles (32.1 km.) east of Colon; sand has to be hauled from about 15 miles (24.1 km.) beyond Porto Bello, and all cement comes from this country and is loaded into barges and hauled up the old French canal to a cement shed. The cement is unloaded from the barges by a traveling crane, and stone and sand are unloaded by cable ways and placed in stock piles near the cement shed. From this cement shed and the stock piles the raw material is transported to the concrete mixing plant by a three-phase,

automatic railway. The cars used on this railway are controlled by attendants at each end of the run. From the mixing plant, the concrete is discharged into buckets set on flat cars, and these cars are then hauled under cable ways along the lock site. The buckets containing concrete are then picked up by the cableways and dumped between the forms. The construction plant has handled about 3000 cu. yd. (2293 cu.m.) of concrete per day. The face forms for the Gatun Lock walls are steel, approximately 36 ft. by 78 ft. (10.9 m. by 23.7 m.) long and are carried on structural steel towers on trucks, on tracks laid parallel with the line of the walls to be formed. There are over 2,000,000 cu. yd. (1,529,100 cu. m.) of concrete in the Gatun locks.

The concrete used on all of the heavy work, not only at Gatun but at Pedro Miguel and Miraflores, is one part cement, three parts sand and six parts crushed stone, but in some of the lighter work a richer mixture is used.

Gatun dam, which will form Gatun lake by impounding the waters of the Chagres river and its tributaries, is 7500 ft. (2286 m.) long overall, measured along the top; is over 2100 ft. (640 m.) wide at the base, about 400 ft. (121.9 m.) through at the water surface, elevation 85 ft; (25.9 m.); and 100 ft. (30.4 m.) wide at the top, which is 115 ft. (35 m.) above sea level. It crosses two valleys separated by a natural hill, in which the works are located for regulating the height of water in the lake. Of the total length of the dam only 500 ft. (152.4 m.) will be exposed to the maximum head of 85 ft. (25.9 m.).

The Gatun dam is truly a great hill constructed by forming two dumps of rocks, obtained from Culebra cut and the lock site, on the outer lines of the structure, and filling between these two lines of rock piles with a natural mixture of sand and clay pumped in by hydraulic dredges from the lake channel and the channel below the dam. The top and up-stream slope of the dam is thoroughly riprapped. The dam when entirely completed will contain about 21,000,000 cu. yd. (16,000,000 cu. m.) of material. At the time of my visit the dam was estimated to be about 90 per cent completed.

Through the hill, located in the dam near the center, an opening 1200 ft. (365 m.) long has been cut through rock to an elevation 10 ft. (3 m.) above sea level. In this opening a spillway dam of concrete is being constructed, which when completed will contain nearly 250,000 cu. yd. (191,000 cu. m.) of concrete.

The floor and portions of the side walls of the Gatun spillway

dam have been built, and during construction of the main dam, all the water discharged from the Chagres river and its tributaries has been flowing through the openings shown in Fig. 16. The sill of the completed spillway will be at the top of the piers shown in Fig. 16, and when it comes time to raise the waters and form the great lake of 164 sq. mi. (425 sq. km.), these diversion channels will be filled up with concrete.

The spillway dam of concrete will have its crest 69 ft. (21 m.) above sea level. Piers 8.5 ft. (2.58 m.) wide will be built on top of the crest, providing 14 openings, averaging about 48 ft. (14.6 m.) in width. These piers between the openings are grooved for gates which will close the openings and complete this portion of the dam. By means of these gates the elevation of the water in the lake will be regulated, and the water discharged over the dam will pass through a diversion channel into the old bed of the Chagres.

The mechanism shown in Fig. 17, for raising and lowering the counterweighted gates, is operated by a seven-h. p. motor placed in the operating tunnel formed in the spillway dam. The water flowing over the dam into the diversion channels will strike against baffles which are intended to reduce velocity of flow.

On the plan view of the spillway is shown the location of the forebay for the hydroelectric plant which is to be built at Gatun to supply the necessary power for the canal operating machinery. This plant will contain three water-wheels, each direct connected to a vertical type, 2500-kw., three-phase, 25 cycle, 2200-volt generator, each generator having a direct connected exciter.

Power supply for the construction equipment is being generated by two steam-turbine-driven plants, one located in a temporary structure at Gatun, and the other in a concrete house at Miraflores. The latter plant will be retained as a reserve for the hydroelectric plant, to be installed at Gatun. In each of these stations there are installed three 1500-kw., three-phase, 25 cycle, 2200-volt generators, driven by steam turbines. The 500-volt direct current for cranes, cable ways, etc., is obtained from synchronous converters installed in these stations.

The enormous reservoir of Gatun lake will be sufficient to store water during the eight or nine months of the rainy season to supply, during the other three or four months, all the needs for lockage in passing the maximum number of ships, allowing for power consumption, evaporation and seepage, and leakage at the gates. As the water surface is to be allowed to rise to refer-

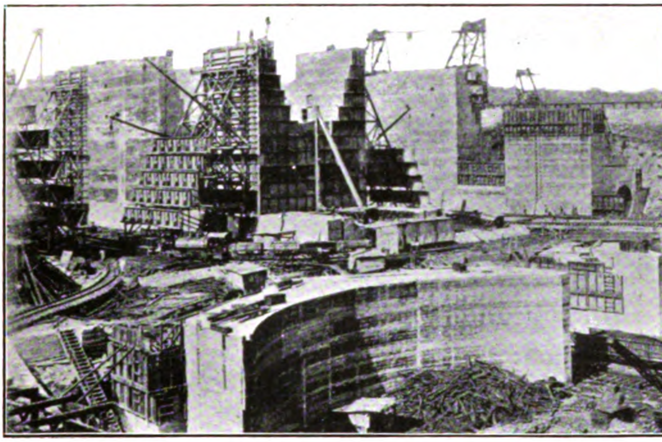


FIG. 15—GATUN LOCK CONSTRUCTION. [EDMONSTON]

FIG. 16—DIVERSION CHANNELS IN GATUN SPILLWAY DAM [EDMONSTON]

[EDMONSTON]

FIG. 18—CULEBRA CUT LOOKING TOWARDS PACIFIC, WITH GOLD HILL TO THE LEFT.

FIG. 19—IN CULEBRA CUT. [EDMONSTON]

ence 87, there will be stored available for the dry season a little more than 5 ft. depth over the 164 sq. mi. (425 sq. km.) of lake area. The average rainfall at the Atlantic end of the isthmus is 130 in. (3.29 m.) per year, and at the Pacific end, abut 70 in. (1.77 m.) per year. The disposal of the water from this great rainfall is one of the difficulties met with in constructing the canal.

Now we will proceed from Gatun, over the lake section of the canal, through which much of the channel depth, not already provided by nature, has been hydraulically dredged, and is now ready for filling with water, to Bas Obispo the Atlantic beginning of the Culebra cut.

The length of this cut is about 8.5 miles (13.6 km.) from Bas Obispo to Pedro Miguel the Pacific end.

The Culebra cut is the most formidable part of the work, simply because of the magnitude of the cutting, and the difficulties which have attended it due to the excessive rainfall on the isthmus, and the varying character of the material encountered in the cut.

Our people continued work in the cut in progress by the French, pursuing the same methods as planned by the French, except as to the character of machinery used, using the old French machinery only until it could be replaced with compressed air drills, giant steam shovels, modern dump cars, etc. The French contemplated a channel through the cut of 74 ft. (22.5 m.) whereas the present plan is for a channel 300 ft. (91.4 m.) wide at the bottom.

In order to drain the cut of water that enters by rains or seepage, a summit has always been maintained in the length of the cut; and the steam shovels have been worked from each end of the cut towards each other and this summit, gradually reducing it. The summit of the excavation in 1904 was at Gold Hill and 193 ft. (58.8 m.) above sea level; and at present is between Empire and the town of Culebra. Thus the water has been drained off from the summit of the cutting, by gavity, to the Rio Grande on the south end, and to the Chagres river on the north or Atlantic end.

Pioneer shovels so called make the first or "pilot cut" for a new lower grade, starting from each end of Culebra cut, which pilot cuts constitute the new drains and to which water is led from the adjacent area by laterals. What water cannot be gotten out of the cut by gravity, is pumped out. After the pilot cut is made, the process of widening goes on, the steam shovels always working with the length of the cut. See Figs. 18 and 19.

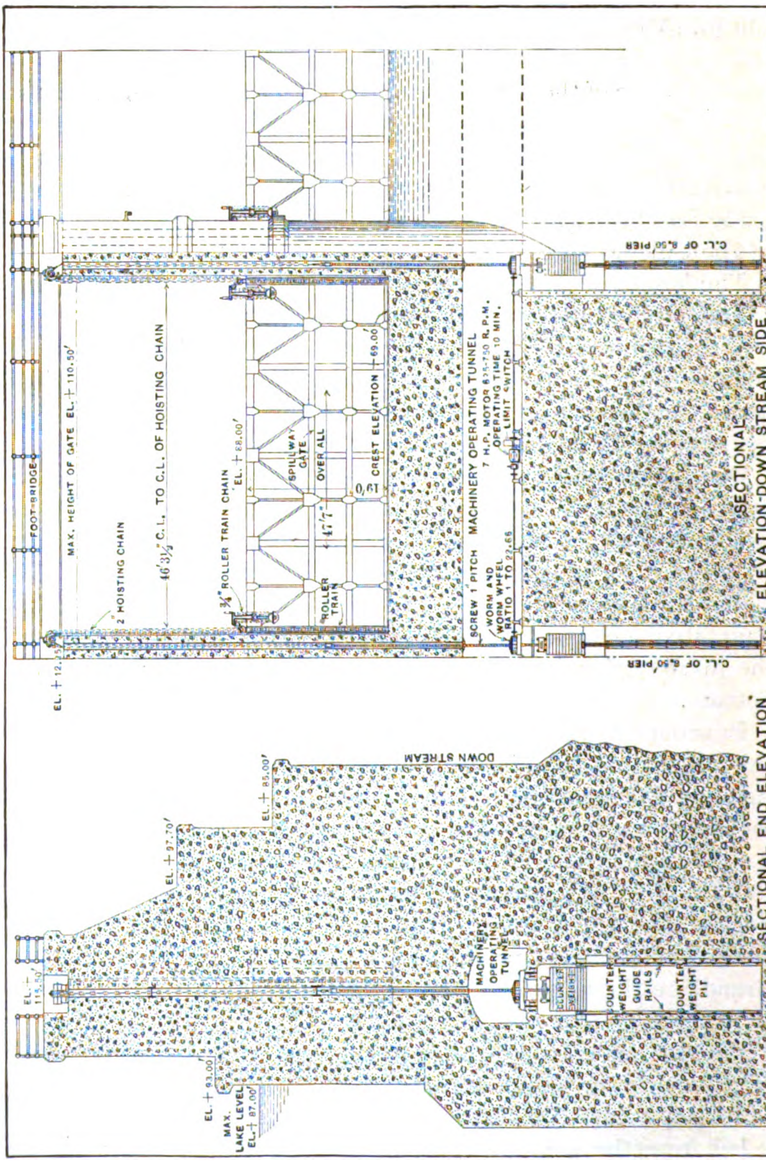


FIG. 17—SECTIONAL ELEVATIONS OF GATUN SPILLWAY

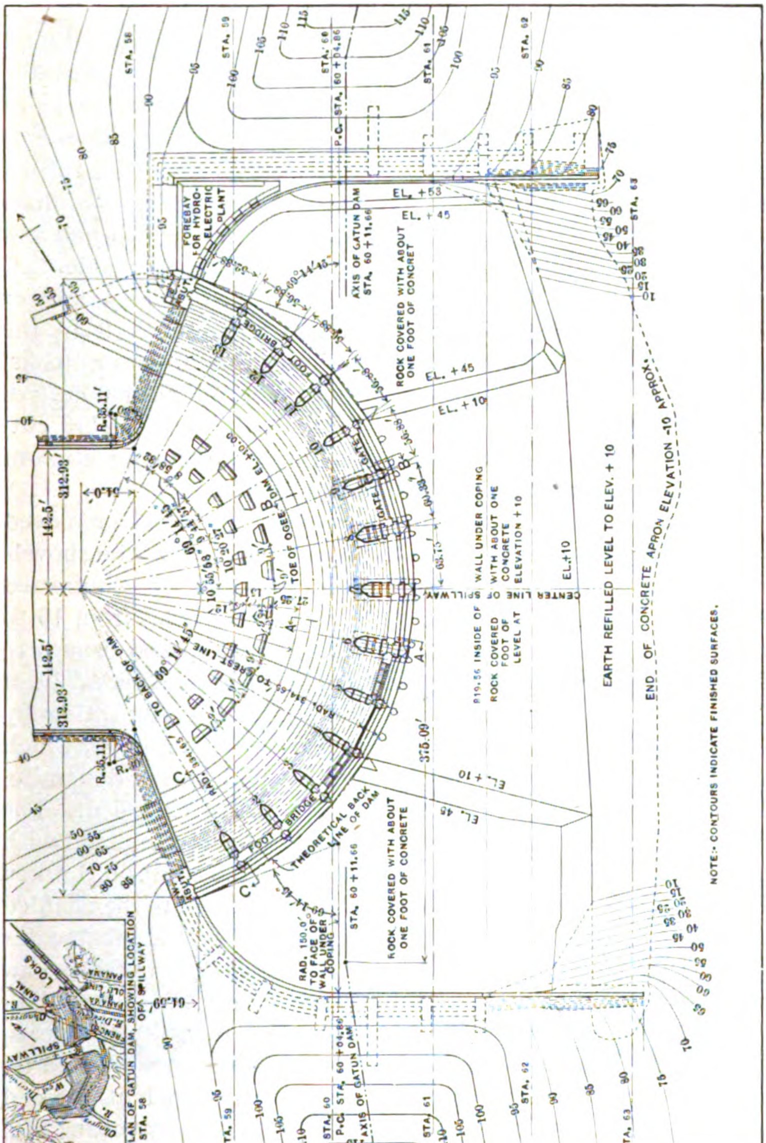


FIG. 17A—PLAN OF GATUN SPILLWAY

One of the great difficulties encountered in the excavation has been due to slides and breaks which cause large masses of earth and rock to slide or move into the excavated area, closing off the drainage, upsetting steam shovels and tearing up the tracks. They have developed as the depth of the cut has increased, and the banks slide or break because of the condition of unstable equilibrium that results from the cutting. There is no way of stopping them and nothing to do but remove the material embraced by them. When grade is reached and the water turned in, the back pressure of the water will result in greater stability, and the slides, if any, that then occur will be relatively small and can easily be handled by the dredges that will be available.

During the twelve months ending July 1st of last year, over 16,000,000 cu. yd. (12,246,400 cu. m.) were taken from the Culebra cut, of which about 30 per cent was from slides or breaks. There now remain probably not more than 10,000,000 cu. yd. (7,654,000 cu.m.) of material to be removed from Culebra cut, provided no extensive new slides develop; and the completion of this cut will mark the date of finishing the canal.

Except in the case of the slides, the material now to be removed from the cut is rock and requires blasting to enable the shovels to handle it. Groups of churn drills, operated by compressed air supplied from three compressor plants drill holes from 15 to to 27 ft. (4.5 to 8.2 m.) deep, which holes are spaced from 6 to 16 ft. (1.8 to 4.8 m.) apart. Into the holes, four to six sticks of dynamite are lowered, and exploded by electric current, thereby forming a chamber for the reception of the main charge, which consists of from 25 to 200 pounds (11.3 to 90.7 kg.) of dynamite. The chamber is then tamped and the charge exploded. The great 95 ton shovels then plow into the blasted section, and with each dip, load from four to five yards (3 to 3.8 cu.m.) of broken stone on to the trains of flat cars. The train loads are then hauled about 11 miles (17.7 km.) to Balboa for building the breakwater or making ground; or hauled to Gatun, or used in building embankments for the new line of the Panama railroad, or for filling in the interior swamps. The cars now used are the steel dumps, which dump on either side, and flat cars which are unloaded by means of a plow and steam winch,—the steam winch at one end of the train drawing the plow from the other end by means of a steel cable. Spreaders and track shifters operated by steam, also aid in the disposal and placing of the spoil.

The Pedro Miguel lock, by one flight, will connect the 85-ft.

[EDMONSTON]

FIG. 20—CULEBRA CUT LOOKING TOWARD THE ATLANTIC FROM THE SUSPENSION BRIDGE AT EMPIRE.

[EDMONSTON]

FIG. 21—PEDRO MIGUEL LOCK LOOKING TOWARDS PACIFIC END

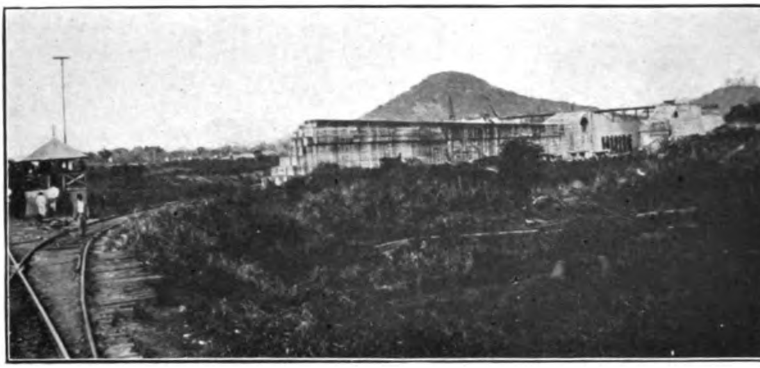
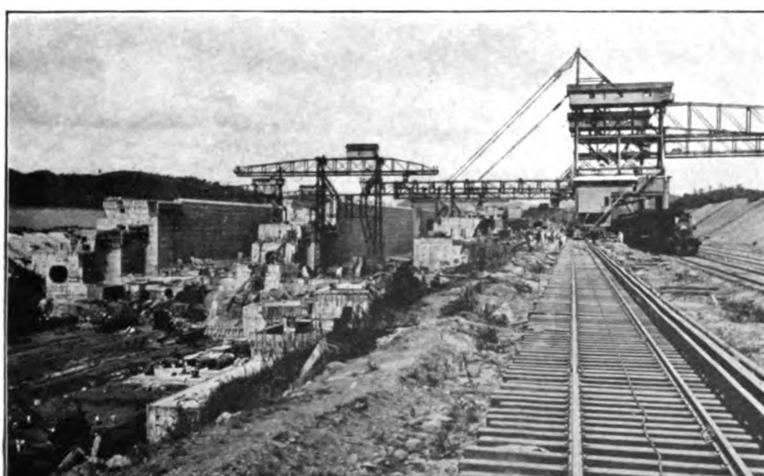


Fig 22—Pedro Miguel Lock, Pacific Entrance. [Edmonston]



[Edmonston]

Fig. 23—Miraflores Locks Viewed from the Pacific End of Upper Flight.

(25.9-m.) level with the Miraflores lake, which will be formed and held at about 55 ft. (16.7 m.) above mean sea level. The dam here connects the head of the lock with the hills to the northwest, and will perform the same function at this end as the Gatun dam at the Atlantic end in maintaining the 85-ft. (25.9-m.) level. This dam of earth, about 1400 ft. (426.7 m.) long, 40 ft. (121.1m.) wide at top at 10 ft. (32.67 m.) above mean tide, is constructed in much the same manner as at Gatun. The side slopes of the dam are 1 on 8, and will be subjected to a maximum head of about 40 ft. (12.1 m.) Concrete core walls connect the dam with the hill and with the lock.

In Fig. 22, showing the Pacific entrance to Pedro Miguel lock, all the land in the foreground will be the bottom of Miraflores lake when the water is turned in. In the distance is shown the east channel entrance in the lock, but the west channel entrance is hidden from view by the center approach wall which extends out.

Proceeding from Pedro Miguel the 1.5 miles (2.4 km.) now ready for the water, brings us to the Miraflores locks and dams, in the course of construction.

These locks, by two flights, overcome the difference in level between Miraflores lake, elevation 55; and the Pacific sea-level section. But with the 20 ft. (6 m.) fluctuation in the tide in the Pacific, the maximum lift for these locks is about 65 ft. (19.8 m.)

All excavation work for the Miraflores Locks has been done, the concrete work for the upper flight is nearing completion, and the floor being laid for the lower flight.

The illustration, Fig. 23, of the Miraflores locks shows clearly the double channel in the locks, and the main culverts in the side and center walls.

The operating machinery of these locks will be of the same design as for Pedro Miguel and Gatun, but the method of constructing these locks, as at Pedro Miguel, has been different from the procedure at Gatun.

The crushed rock used in the concrete at Pedro Miguel and Miraflores is obtained from the quarries and crushing plant on Ancon Hill, and is hauled down grade by rail some 4.5 and 3 miles (7.2 and 4.8 km.) respectively. Sand is obtained from a sandbank at Chame, on the Pacific about 23 miles (37 km.) up the coast; it is brought by barges to the docks at Balboa, unloaded into bins by electric cranes; and thence hauled to the lock

sites, and the cars run up on trestles on the side of the lock sites. Sand is dumped on one side of these trestles, and crushed stone on the other side, thus forming the stock piles. Cement comes from the Atlantic side by rail.

At Miraflores, four cranes, designated chamber cranes, operate in the lock chambers, and two cranes on each side of the lock site operate on top of the side banks or berms of the lock-pit and are called berm cranes. The fixed cantilever of the berm cranes extends over the stock piles, as shown in the illustration, and handles the stone and sand by grab bucket to the hoppers of the mixing plant which is located in the lower part of the crane tower. The concrete is then discharged from two-yard (1.5 cu. m.) cubical mixers, into dump buckets set on a platform on the opposite side of the tower, picked up by the hoist and trolley on the hinged boom, and either deposited in the lock side walls or transferred to the chamber cranes to be placed in the center wall, or the floor. Cement in bags is delivered direct from the cars to a platform above the measuring hoppers. These cranes are all operated by direct-current motors.

At Pedro Miguel and at Miraflores, wood forms or centering of the cantilever type are used throughout in the forming of the walls, instead of using steel face forms as at Gatun. The wood forms are held by greased bolts to the lower part of the concrete that has set, and are used over and over again, being raised as the concrete work is carried up. The concrete work at these two places has cost less than at Gatun, about $4.70 against about $6. 60 per cubic yard (0.76 cu. m.) including plant charges and division expense, which is due in part to the lower cost of the crushed stone on the Pacific side.

At Miraflores, an earth dam is thrown across from the head of the west lock wall to Cocoli Hill. The dam is constructed in the same manner as the Gatun Dam; it is 2300 ft. (700 m.) long, top width 40 ft. (12.1 m.) at elevation 70; and the side slopes are 1 on 12. This dam will be subjected to a maximum head of 40 feet (12.1 m.)

From the head of the east lock wall to a nearby hill, a concrete dam about 500 ft. (152.4 m.) long is being provided. In this dam there is a spillway with regulating works similar to that at Gatun. This spillway has seven openings, the sill of which is at elevation 39, and will permit a discharge of 7500 cu. ft. (212.4 cu. m.) of water per second. The water discharged over this spillway will flow into the Rio Grande.

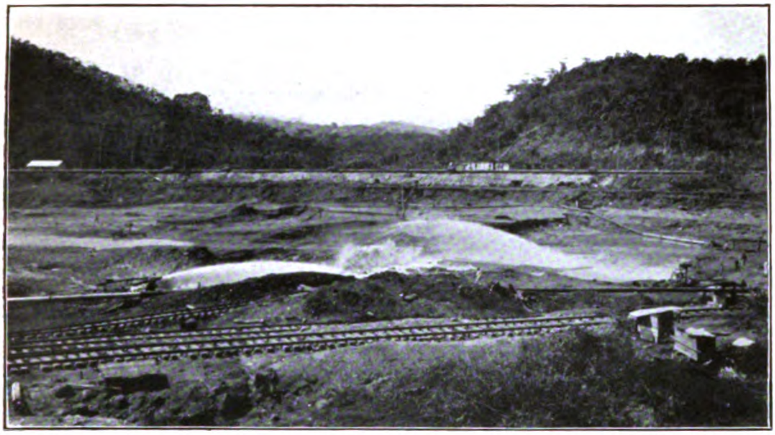
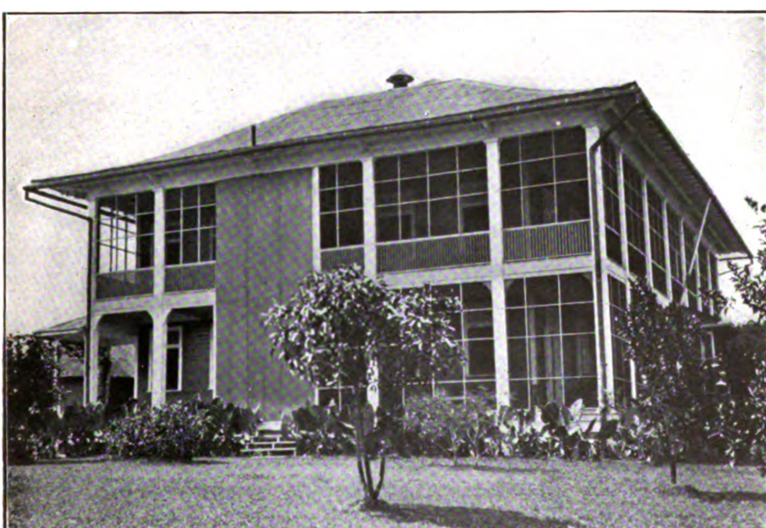


FIG. 24—HYDRAULIC DREDGING OF CANAL ON PACIFIC SIDE. [EDMONSTON]

FIG. 25—SEA LEVEL PACIFIC SECTION. [EDMONSTON

FIG. 26—BREAKWATER AND PACIFIC ENTRANCE TO CANAL. [EDMONSTON]

FIG. 27—CENTRAL AVENUE, PANAMA CITY. [EDMONSTON]



[EDMONSTON

FIG. 28—RESIDENCE OF COL. GEO. W. GOETHALS AT CULEBRA.

In 1.5 miles (2.4 km.) of the channel section from Miraflores towards the Pacific, rock was found, at elevation minus 30. This rock is overlaid with loam, and to cut the requisite depth of channel it was deemed advisable to remove the loam by a hydraulic excavating plant, and then remove the rock is the usual way. The illustration, Fig. 24, shows a portion of the hydraulic excavating plant in operation. Four hydraulic pumps force water through pipes to water jets or hydraulic giants, which play the water, at a pressure of about 130 lb. (58.9 kg.) on the loam, washing it to sumps, from which 18-in. (45.7-cm.) centrifugal pumps, mounted on concrete barges, pump the material through pipe lines to reclaim swamp land. The method of procedure was to float the concrete barges containing the dredging pumps, after isolating a section by dykes at each end, and then pump the water out until there was just sufficient to float the barges at the lowest level. The giants would then be made to play on the soil around the barge; and the barge settled in the sump thus formed. The giants would then sluice to the suction pumps until there was insufficient slope of the silt to flow; when the barge would be floated to another point. The suction pumps on these concrete barges are driven by 650-h.p. three-phase, 25-cycle, 2200-volt induction motors, which are fed by lead covered submarine cables, from distributing points along the channel.

From a point 1.5 miles (2.4 km.) from Miraflores locks, to deepwater in the Pacific, a channel has been cut by ordinary dredging operations. Any submerged rock encountered in this portion of the channel, which the dredges cannot handle, is drilled from a drill-scow and then blasted.

The illustration, Fig. 25, was taken from a point opposite Balboa, looking northward towards Miraflores locks.

The portion of the canal out into the ocean, is about completed.

At Balboa the docks and marine shops are located, and an extensive system of new docks is now in course of construction, where the ships of the future can tie up and transfer freight.

The illustration, Fig. 26, was taken from the breakwater which is being extended from Balboa to Naos island, a distance of 17,000 ft. (5181 m.). In the illustration, to the left of the breakwater and parallel with it, is the canal channel. In the distance, in line with the breakwater, is Balboa, beyond, is Ancon Hill; and east of Ancon Hill, to the left in the picture, Panama City is located, almost at the foot of the hill.

From deepwater in the Caribbean Sea on the Atlantic side, to

deepwater in the Pacific, the entire canal channel will be adequately lighted and marked by buoys. Many of the concrete range-light towers are now in place, and it was an odd sight for us to see some of these light-houses, located in the interior, now in jungles.

For the first several years after the United States took hold of the canal work, efforts were directed principally towards preparing properly to cope with the great undertaking. A working force had to be recruited and organized, suitable houses and hotels constructed, food supplies arranged for, and adequate machinery and plant provided for efficiently doing the work.

The unsanitary condition of the isthmus, and diseases resulting therefrom, was one of the greatest contributing factors to the failures of the French; and one of the first great preliminary works our people did was to clear and drain the lands, fill all pools in which water could stand, and oil all the banks along the small streams to exterminate the mosquito and the fly. This sanitary work was under the able direction of Col. Gorgas, who gained his experience in Cuba; and that he has done his work well is attested by the fact that the death rate on the isthmus is now much less than in many of our cities; and it is a rare thing to see either a fly or mosquito.

A splendid lesson which we can draw from this sanitary work on the isthmus is that in our cities and villages we can exterminate flies and mosquitos, carriers of many diseases, especially fevers such as malaria or yellow; and as Dr. W. S. Thayer recently stated at the Academy of Medicine in New York, the national neglect of malaria prevention is a national disgrace, accentuated by the magnificent results of American sanitation campaigns in the Panama zone.

Both Colon and Panama City, before our people went to the zone were pest holes; but our Americans built sewers, paved streets, and established and maintained strict sanitary regulations, so that these two cities are now healthful cities.

This house shown in Fig. 28, is typical of the houses which have been built by the Americans on the Isthmus, and though one of the best, it is not very pretentious.

Panama City is a town of low buildings, and very few of the Americans reside in the city, but live in small towns and villages dotted over the zone from the Caribbean to the Pacific. About 40,000 workers are so housed.

The Canal officials estimate that the canal is about 90 per cent

completed, and they confidently expect to see vessels passing through the canal in the year 1914.

The work on the isthmus is splendidly organized; it is being vigorously pushed, and apparently, is being done most efficiently.

Among the dozens of engineers and heads of departments whom I met during my week's stay, I saw no signs of military pomp or ceremony. The men who are doing the work are clean-cut, modest, business-like engineers, interested and enthusiastic in the work; and to Col. Goethals, great credit is due for this personnel and the fine example he sets his men.

For much of the information given, I am indebted to reports by Col. Geo. W. Goethals and the Isthmian Canal Commission.

DISCUSSION ON "THIRTY YEARS' PROGRESS IN THE ELECTRIC FURNACE" (FITZGERALD), BOSTON, MASS., JUNE 25, 1912. (SEE PROCEEDINGS FOR JUNE, 1912.)

(Subject to final revision for the Transactions.)

Carl Hering: I am very glad to see that Mr. FitzGerald emphasized the fact that the cost of the energy is not the principal item in an electric furnace; so many people seem to think that it is; the cost of the electrodes, the cost of the furnace, the saving of labor, the better quality of the product, etc., should also be considered. If the product is more valuable you could stand a greater cost, and if the electric furnace should save labor, a very little labor cost will pay for much energy. Mr. FitzGerald speaks of using fuel heat in conjunction with electric heat. It seems to me it is better to use them in series than in multiple, to use electrical terms, that is, not to use them simultaneously, but to preheat with fuel and then get the higher temperatures by electric heat; the heat absorbed by preheating the metal will be found to be quite a large part of the total. Connecting carbon electrodes together, to avoid butts, gets over some of the electrode trouble, but on the other hand that junction is liable to break, allowing the butts to drop on to the bath, and to get those butts out of the bath is sometimes a very serious matter.

Alfred H. Cowles: Mr. FitzGerald has mentioned the Siemens furnace as a forerunner. I think we might as well go back to Sir Humphrey Davy's work in 1807 and 1808 as the forerunner. In 1885 the Siemens patent and work was encountered by my brother and myself in looking up the literature on electric furnaces. We found that Sir William Siemens had at the Paris Exposition in 1879 melted some iron in crucibles with an arc, but provided no method of confining the heat. His brother Dr. Werner Siemens has stated that Sir William Siemens never thought of the idea of reducing metals in his electric arc furnace. He had no bath or flux on top of the molten metal which might furnish resistance for the current to pass through, and therefore I think that his work cannot be considered in any manner an anticipation of the splendid work done by Heroult in evolving a resistance material in the form of a flux on top of his bath of molten iron. Mr. FitzGerald in referring to the work of my brother and myself spoke of it as a small work that we had done. In 1885 we ordered the largest of dynamos, in amperes, ever made up to that date, and after that we ordered the largest dynamo in watts, ever specially designed for the purpose of operating electric furnaces. In 1886 we again ordered the largest dynamo (500 e.h.p.) ever designed up to that year, and after that ordered three more, the largest 700 h.p. All this work was done before a stroke of work was done at Niagara or by Acheson at Monongahela City. The production of calcium carbide, and of carborundum, although the latter's name was not then given to it, was accomplished in our work and a sample was left from 1887 until about 1898 in the Massachusetts Institute of Technology Museum, and in litigation that followed, that sample was produced and the

U. S. Court of Appeals in Philadelphia* decided that the Cowles brothers had not only made crystalline carbide of silicon four years ahead of Acheson, but had anticipated Acheson by one of our process patents. It took about six years to settle this litigation, and it is not entirely settled yet, after eighteen years have passed, as the damage case is now in the hands of the same court.

I dislike to speak in my own behalf, but when one meets a party of electricians in 1912, who are not familiar with what was going on in 1885 and '86, it seems necessary to say that between that time and this a great many of the facts have become twisted in the literature. In 1885 and '86 the literature was full of our work. In 1885 Dr. T. Sterry Hunt visited our works and asked us to repeat some tests for him. He stated to us that, from theories of his own, he believed the specific gravity of fused quartz should be 2 instead of $2\frac{1}{2}$, that of crystalline quartz. The experiment made for him developed the specific gravity as about 2.15. He described this work on silicon and other reductions of the then rare elements by us in the Proceedings of the American Institute of Mining Engineers at the Montreal meeting, I think in 1886. We had melted and reduced $Si\,O_2$ before that time, and in the reduction retorts we found a suboxide of silicon. In the experiment that we made we found a yellow substance lying between the unreduced silica and the crystallized carbide of silicon. This was analyzed and found to be a suboxide of silicon and described by Professor Charles Mabery before the Franklin Institute in 1887, I think, and before other scientific bodies. It is now called siloxygen. The carbide of silicon that we made we mistook for DeVille's crystalline silicon. We also found amorphous masses which analysis showed to be silicon. In those experiments we obtained both the Si and SiC. While we did not analyze and discover the composition of carbide of silicon, we did produce it; and it was only during the litigation that we sent to the Massachusetts Institute of Technology and secured a sample of carbide of silicon that had been left there (after a lecture given by myself in February, 1886), and had it analyzed; and had its crystalline structure examined by Professor Robert H. Richards, the curator of the museum of the Massachusetts Institute of Technology. It was ascertained that we had formed the carbide of silicon about four years previous to Acheson's earliest work. The discovery that carborundum was a carbide of silicon was made by Mr. Muhlhauser, if I recall the name correctly, who about a year and a half after the first experiment with the furnace by Acheson in 1889, while in Acheson's employ, analyzed the substance and ascertained the true composition of it. I think that this gives the first record of this work on carborundum, which has not recently appeared in the public prints, but has appeared in the court discussions bearing on this subject.

*Page 683, *Federal Reporter*, No. 102.

W. B. Jackson: I would like to ask one question, and that is whether at the present time there is any likelihood of the electric furnace being constructed in such a manner and working in such a manner that it may become a valuable operation in valley power. My idea was that such a furnace might be very properly adopted for the use of such power.

F. A. J. FitzGerald: In regard to Mr. Cowles' remark, when I spoke of the Cowles furnaces being small, I meant that while they had furnaces having a capacity of perhaps 750 kw., then, they are small compared to some of those used today. They were the largest furnaces used at the time, far and away greater than those used in Europe or anywhere else; I meant small only in comparison with some of the 6000-kw. furnaces in use at the present time.

In regard to the question of valley power, we are working on that question now. For certain purposes you cannot use discontinuous furnaces. But there are certain conditions under which the electric furnace would be extremely useful for short runs of 8 hours.

I have been asked to explain how I would water-cool these electrodes if they were threaded and spliced. The water-cooled head is a ring that grasps the electrodes. The electrodes are threaded so that they may be screwed together and are slipped down through the ring as they wear away.

Discussion on "Electrical Measurements with Special Reference to Lamp Testing" (Edwards), and "Incandescent Lamps as Resistances" (Amrine), Boston, Mass., June 28, 1912. (See Proceedings for June, 1912.)

(Subject to final revision for the Transactions.)

Clayton H. Sharp: Speaking of the paper by Mr. Edwards, the author gives a curve of corrections for the alternating-current voltmeter as used in checking the voltages on the life testing rack. He emphasizes the importance of that correction curve. I do not think he emphasizes it quite enough and I doubt if a laboratory standard voltmeter alone, even though carefully checked, is quite sufficient to maintain the very high degree of accuracy which is called for in the measurement of life testing voltages. One-tenth of one per cent on the life testing voltage will make several per cent difference in the life of the lamp, and may have very serious commercial results under certain circumstances; so that in all lamp testing, the most important thing is the accurate determination and checking of these voltages. No single method is sufficient, but rather, various methods must be used and checked against each other. For instance, in our own laboratory, we use a multicellular electrostatic voltmeter with a mirror and scale, a method introduced by Dr. Kennelly some years ago. This is used as a transfer instrument to check directly against the potentiometer, so that the chances of errors of the instruments themselves are as nearly as possible eliminated. Other instruments are used in the same way.

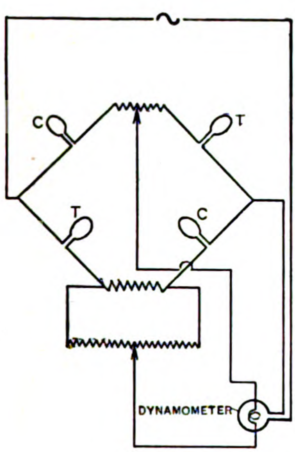


Fig. 1

More recently we have been trying the method suggested by Mr. Amrine, namely the use of the old Howell indicator. See Fig. 1.

The bridge which we have used is made up of tungsten and carbon lamps in opposite arms. At one diagonal of the bridge is placed a resistance of zero temperature coefficient. About this is looped a rheostat of high resistance with a rotating switch, making a very great many contacts.

The bridge is placed on the circuit the voltage of which is to be measured and in series with it is a fixed coil of a sensitive electrodynamometer. The moving coil, which is supported on a suspension wire and carries a mirror, is placed across the bridge in the usual connection for the galvanometer, excepting that one connection from it is made to the rotating switch of

the rheostat. With this arrangement properly adjusted, the different positions of the rheostat arm correspond to different voltages on the bridge and the rheostat may be calibrated to read in volts. It is used as a transfer instrument, being calibrated on direct current. On account of the slight lead which the current has in a tungsten lamp on alternating current due to the considerable changes of temperature, of the filament the bridge does not give correct results as a transfer instrument if the lamp filaments are too fine. It is necessary therefore to use lamps of fairly high candle-power in the construction of the bridge. The lamps must be of the same quality and character as are used for precise photometric standards; that is, all loose or variable contacts in the interior of the lamp must be eliminated and the lamps should be properly seasoned or aged before put into the bridge.

It should be noted that an arrangement of this kind is extremely sensitive to differences in voltage. Differences of 0.0001 of a volt in 100 volts; that is, differences of one part in 1,000,000 are shown by the deflection of the electrodynamometer.

Referring again to Mr. Edwards' paper, he says that in commercial testing the ordinary portable instruments are insufficient. That is quite true, and a larger type must be used. For more careful measurement it is better to use two potentiometers, one for measuring voltage and the other for measuring current.

As to the indicating instrument on the switchboard for the life test voltage, another possible modification of that scheme is to give the man who regulates a single, positive mark to go by, so that he has not any chance to estimate or to do anything else. He merely holds his needle on that mark, which relieves him from a large amount of mental exertion.

A. E. Kennelly: This description which has been given us by Dr. Sharp is very interesting, in regard to that kind of voltmeter, and I quite agree with the opinion he expressed, that no one particular instrument should be taken as the exclusive court of appeal in deciding the calibration of an alternating-current voltmeter. Checks should be obtained in all cases. We have found that the alternating-current potentiometer of Dr. Drysdale is a very useful and convenient check, which, by means of the vibration galvanometer, gives a high degree of sensibility, enabling a difference in voltage of one-twentieth of one per cent to be easily determined.

M. G. Lloyd: I should like to ask Mr. Edwards a few questions, and to have him elucidate Fig. 3 a little further. First, in regard to how the settings were made on which these readings were taken. There might be three ways of making these settings: In one way they would be evenly scattered across the entire scale; in the second way, they might be set on the exact tenths rigidly, and the same number of settings made on each tenth division; and in the third way they would be left to chance, and, on account of something in the set-up, they might fall more fre-

quently in one region than in another; so I should like to know how the settings were made from which these readings were taken.

Secondly, I think the width of the space is a very important thing in a study of this kind, as it seems to me the tendency exhibited in these results would very largely depend on the ratio of the width of the pointer to the width of the space.

Paul MacGahan: I wish to point out an interesting application of the tungsten lamp used as a resistor. This is in connection with contact-making voltmeters, such as are often used for potential regulators, or in relay type graphic meters, in which the tungsten lamp is used as a resistance between the contact and the magnet or motor. The idea is to introduce a low resistance just when the contact is made, giving a good starting characteristic to the device, and improving the contact action. As soon as the contact is made, the lamp lights up and increases in resistance ten times, and thus greatly reduces the current and sparking when the contact is broken.

T. H. Amrine: In Mr. Edward's paper, he mentions the use of graphic recording voltmeters on life testing lines. He is correct, of course, in his statement that the ordinary graphic voltmeter cannot be depended upon for anything more than to show very large changes in the voltage and to show interruptions in the service. The photographic recording voltmeter which is mentioned in my paper is being developed for this service and the indications are that it will serve the purpose well. It is sufficiently sensitive and has a sufficiently wide scale so that variations of one to two-tenths per cent in voltage are plainly indicated on the chart.

A couple of records from this photographic recording voltmeter are presented herewith, which show what can be done by the instrument. They also serve to show the sort of voltage regulation that can be obtained on alternating-current lines by means of the automatic voltage regulator under the best conditions. The original of chart No. 1 was taken with the voltmeter adjusted to give a scale of 1.8 in. (145.7 mm.) per volt. The original of chart No. 2 has a scale of 1.5 in. (38.1 mm.) per volt.

Evan J. Edwards: Referring to Dr. Lloyd's question as to the method used in obtaining the readings of Fig. 3, I would say that these figures were taken from old photometric data which were obtained with no thought that they might be used for the purpose of this investigation. Only such readings as were obtained in a straight estimation of tenths between smallest divisions, were selected; that is to say, only such groups of data as could be expected to show a nearly equal number of occurrences of each digit for a large number of readings were included.

The width between smallest divisions used in obtaining the curves of Fig. 4 was that of a standard portable voltmeter having 150 scale divisions.

DISCUSSION ON "THE VIBRATION OF TELEPHONE DIAPHRAGMS" (MEYER AND WHITEHEAD), BOSTON, MASS., JUNE 27, 1912. (SEE PROCEEDINGS FOR JUNE, 1912.)

(Subject to final revision for the Transactions.)

George D. Shepardson: Attention is called in the paper to the irregularities in the oscillograph curves at the values 332 cycles and 1292 cycles. I examined that "dimple," as it is called, with considerable interest, and found two possible explanations for it. In both cases the dimple occurs where the diaphragm is at the greatest distance from the magnet. The first explanation which occurs is that the diaphragm is there in a comparatively weak field where the diaphragm is more free to vibrate in its own natural periods. Another more plausible explanation is that the actuating current in this case is several hundred times greater than the normal current. Now, that means, if we refer to the equation which is given here for the performance of the diaphragm, a very strong m.m.f., due to the current in the coil. At the "dimple," the current in the negative or demagnetizing direction becomes dominant and neutralizes the m.m.f. due to the permanent magnet; as the current passes the critical value, its pull becomes positive, being proportional to the square of the current, and thus causes the "dimple" at the extreme value. I think this second reason is much more plausible than the first, that is, that it is the m.m.f. of the current overcoming and reversing the permanent field.

That suggests a point in connection with the equations (**2**) and (**3**). You will find that all of the discussions of the theory of the telephone transmitter are based on the assumption that the current in the coil actually changes the value of the permanent field. I think that is entirely erroneous. If you place a coil about the heel of the magnet, at the most remote distance from the coils, you will find that the variation in the permanent flux is almost nil; it amounts to from 1 to 10 per cent with the greatest possible variation in the inductance you can get, by removing the armature entirely away from the soft iron pole pieces. It seems to me, the real action of the current in the coil on a telephone receiver is not to change the total amount of flux but simply to change the distribution of it. I doubt very much whether the total flux passing through the diaphragm is even changed, but the action of the coil is to concentrate that force.

Inquiry is made about the discrepancy between the natural period as observed and that as calculated, 890 in one case and 732 in the other. I suggest that that discrepancy may be due to the fact that Rayleigh's formula does not take very much account of the temperature effect. The temperature acts very much like the cords of a drum. You tighten up the cords on the drum and the tone of the drum rises, and so in the case of the telephone receiver, as the temperature rises it strains the diaphragm and raises its natural period of vibration. Rayleigh's formula does not specifically cover that point. In the case of the trans-

mitter diaphragm, clamped only at one or two points, and if there are other points these are usually in a straight line, the temperature effect is almost nil. I have applied temperature variation of 100 deg. fahr. to a transmitter diaphragm and found no appreciable difference in the sensitiveness to sounds of varying pitch.

Mention is made of the effect of the damping spring. I have experimented recently upon a transmitter where the source of sound was a siren whose speed and whose pressure were separately controllable, and I found in almost every case a curve of sensibility which bears a general family resemblance to Fig. 16 of the paper. The effect of the damping spring upon the natural period does not seem to be as great as one might expect, although it does seem to have some influence. In one case I found a minimum sensitiveness at 1115 vibrations, with the damping spring removed clear off to one side. With the damping spring shifted back to its ordinary position, and with the ordinary tension, the maximum point was at 1070 vibrations. By tightening the damping spring, moving the screw in about one-quarter turn, the maximum point was shifted over to 975, so that the presence of the damping spring seems to affect the pitch for maximum sensitiveness. These results were not repeated, and I do not attach great importance upon them.

Regarding the positions of maximum sensitiveness in the curve of Fig. 16, experimental work shows that these positions vary according to the construction of the transmitter, that is, transmitters of different manufacture will show these points of maximum sensitiveness coming at varying positions. Different transmitters from the same factory will show marked differences in the positions of the peaks. For example, one transmitter showed minor peaks at about 500 cycles per second, and major peaks at some 925 cycles per second, another at 1065, another at 1655, and another at 2100, so you may expect a series of peaks of maximum sensitiveness. In another case the peaks came at 1600, 900, 1065, and 1640, and this case of 1640 was what I would call the *summum maximum*, that is the highest, higher than any of the other peaks. Another transmitter had equal maxima at 1050 and 1700.

I would say that these experiments were made with sound as the source of the disturbance, and there was considerable difficulty experienced in getting rid of reflections from the walls. In some cases these brought in phenomena that were very puzzling until means were found to eliminate them.

George W. Pierce: I have been very much interested in this paper, particularly as Professor Kennelly and I have recently been making some experiments[1] which include as a part of the work the determination of the period of vibration of the telephone diaphragm. First, as to temperature. One of our

1. Published in full in Proc. Am. Acad. (Boston), Vol. 48, No. 6, 1912.

laboratory mechanics, Mr. Greaves, who was trying to make a telephone of particular pitch, found when he breathed on the diaphragm he changed the period perhaps fifty per cent. The period changes enormously if the diaphragm is rigidly clamped into a metallic frame, but if the diaphragm is loosely clamped, as in the case of the ordinary telephone receiver, with washers or gaskets, the temperature does not have so great an effect.

In regard to the occurrence of the dimple in two or three of Meyer's and Whitehead's oscillograms, also with some oscillograms similar to these, I found that the dimple occurred when the current was large, independent of the pitch, and it seems to me to be the phenomenon that Professor Shepardson has mentioned, of the preponderance of impressed force over the directing force of the permanent magnet. To avoid that effect I found that, if you use a permanent magnet for the field and attach a coil to the diaphragm, so as to link with the magnetic flux of the field magnet, and send alternating current through the coil, you can vary the pull on the diaphragm to any extent, yet get no dimple at all, because there was no change in the B_0 magnetic field by the effect of the impressed current.

In regard to the period of the diaphragm, Professor Kennelly and I have been measuring resistances and inductance of the telephone receiver at different frequencies, and the result is very interesting and indicates the marked effect of periodicity of the diaphragms as Messrs. Meyer and Whitehead have found. If you measure the resistance and the inductance with the telephone diaphragms damped you get one value, and then, if you take your finger off the diaphragm, and allow it to vibrate, you get a different value of inductance and resistance.

With the diaphragm vibrating, the inductance and resistance may differ by 50 per cent from the inductance and resistance with the diaphragm damped. Let us call the excess of the inductance or resistance when the diaphragm is free over the inductance or resistance when the diaphragm is damped *the motional inductance or resistance* of the receiver. The motional inductance multiplied by the angular velocity we shall call the *motional reactance.* If now we plot motional resistance and motional reactance against the angular velocity of impressed e.m.f. we get —for a particular receiver—the curves marked "reactance" and "resistance" in Fig. 1. At the pitch of 5700 radians per sec. the vibration of the diaphragm increases the resistance by a large amount (22 ohms). At a slightly different pitch—5900—the vibration of the diaphragm decreases the resistance by (45 ohms). The reactance may follow a curve somewhat like the resistance curve but in general with the change of pitch, the vibration of the diaphragm causes the reactance to decrease to a minimum and then to go up again, as shown by the curve marked "reactance."

Now, if we measured the inductance, calculated the reactance and measured the resistance, we had the impedance, also we knew

the current—and, multiplying the square of the current by the resistance, you get the power, and taking the difference between the power when the telephone is free and vibrating, and the power when the telephone is damped, you get the curve marked "power" of Fig. 1. The change-of-power curve, the amount of power supplied to the telephone when free in excess of the amount when damped is very large when you approach the resonant period of the diaphragm, and attains its maximum in the neighborhood of natural period of the diaphragm, which in the case of Fig. 1 was 5820 radians per second. This change of power amounted to as much as 68 per cent, when the telephone was making a pretty good noise. That is, if you put your finger on

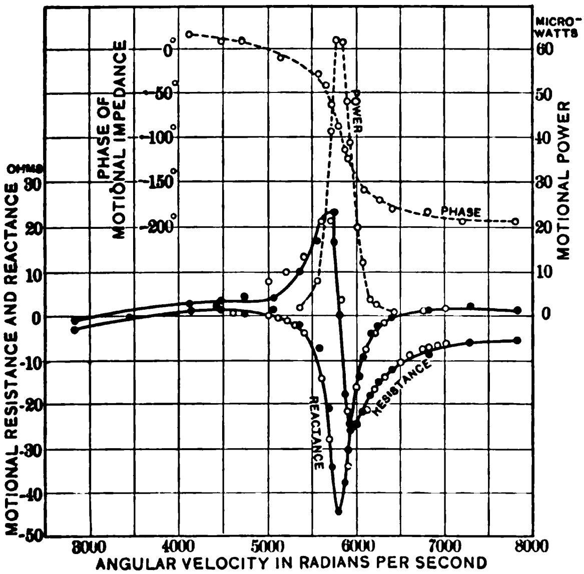


FIG. 1

the diaphragm and measured the power input at constant voltage, and take your finger off the diaphragm, and then measure the power input, you will find that the power input has increased by 68 per cent.

The telephone was free in a room, and the room was full of sound, when we were using current of frequency near the resonance point, and the sound interfered by reflection producing stationary waves in the room. If an assistant walked through the room, so as to go through the different points of maxima and minima of sound, the effect is a reaction on the telephone, so that its inductance and resistance changes with the position of the assistant in the room, and if you had a bridge balance for inductance and resistance and allowed a man to walk through

the room, the bridge would be variously thrown in and out of balance. The reflected sound, coming back and striking the diaphragm, determine in part the work by the diaphragm, so that a shift of the stationary wave system in the room, affected inductance, resistance and power. With a given e.m.f. the resistance of the diaphragm would usually increase with the amount of work done by the diaphragm, and that would depend upon the stationary wave system.

If you plot the motional reactance against the motional resistance—meaning by the motional values the excess of reactance or resistance when the diaphragm is free over the corresponding value when it is damped—if you plot one of these quantities against the other, *R* being plotted horizontally and *L* being vertical, you get a circular locus, as in Fig. 2. The resistance and inductance change in relation to each other. The position of the center of the circle is determined by the mechanical and electrical constant of the diaphragm, and if you plot angular velocities of impressed e.m.f. around the circle, you begin at the origin with angular velocity zero, and as the angular velocity increases to infinity the vector " motional " impedance goes once around the circle in a negative direction. The frequency of e.m.f. which gives this point of the impedance circle diametrically opposite to origin is the natural frequency of the diaphragm; and the periods of the diaphragm differ in different instruments and also the sharpness of these resonance curves differ in different instruments. If you take a curve like that, which Messrs. Meyer and Whitehead have in their paper—or the resonance curve of the excess power put into the telephone when the diaphragm is free, you find that with an ordinary Bell receiver, the change of frequency to throw the diaphragms well out of resonance may be as much as 100 radians per second, but if you take a diaphragm rigidly clamped around the periphery by a heavy metallic clamp a change of period of 10 radians per second in five thousand would throw it completely out of resonance and reduce the amplitude of vibration so as to give almost complete silence. If you breathe on the rigidly-clamped diaphragm when it is actuated by a resonant current, the heat of the breath may so change the natural mechanical period of the diaphragm as to produce complete silence.

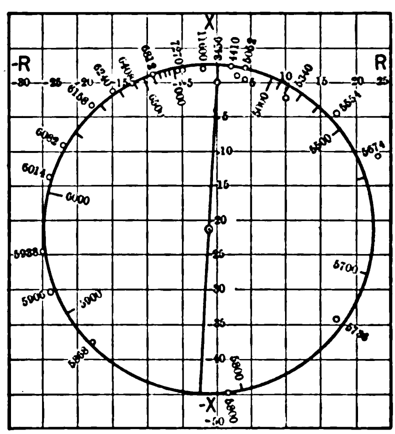


Fig. 2

Professor Kennelly and I find that the curves that I have shown agree closely with theoretical values obtained by considering the reaction of the moving membrane on the magnetic circuit. The theoretical treatment resembles the theoretical discussion of refraction and absorption in the neighborhood of the absorptive band in optics, except that in the telephone diaphragm problem account had to be taken of the fact that the magnetization of the iron lags behind the magnetizing forces consequently the shift in phase in the telephone problem differs from that in the optical problem. We determined experimentally the shift of phase, and found that it was equal to twice the angle of lag of the magnetization behind the magnetizing force as was demanded by the theory.

Alan E. Flowers: I ask what bearing your results have on the values that have been given for the principal frequencies in telephone currents; and also, if it is possible in further experiments to use a diaphragm which would be free from enamel or other nonelastic substances, so that the period could be calculated more accurately, and if possible have the surfaces polished so that you would get the reflection from different portions at will without loading any particular spot? The very small mirror may or may not have some effect upon some particular laws of diametral vibration, depending, of course, on the relation of the weight of the mirror per unit area and the weight of the diaphragm itself per unit area; and, further, if it would be posisible to carry out further experiments with different diaphragm thicknesses?

A. E. Kennelly: There seems to be a difference of phase indicated in some of the oscillograms, judging from a merely random examination, between the currents and the motions, and we should be glad to know whether that difference actually exists or not.

John B. Taylor: Dr. Kennelly asked the question I was about to ask; that is, whether the apparatus is set up with sufficient exactness so that measurements made from the current to the diaphragm displacement line can be taken as indicating the relative phase between the two. Some of the records at low frequency seem to show more pronounced lags than those at higher frequency, and one of the records, in Fig. 4, seems to show almost a reversal. It is possible in this case they may have taken their apparatus down and set it up again with connections reversed.

John B. Whitehead: Which one?

John B. Taylor: The one I call a reversal, as it appears so to me, is 9.8 radians.

John B. Whitehead: What is the frequency?

John B. Taylor: It is 1066, as given on plate LVI.

John B. Whitehead: There are some of these which are quite extreme.

John B. Taylor: 9.8×10^{-4} radians deflection under 1066 cycles

seems to show a distinct reversal. Some appear to lag and others to lead.

Another point is, whether the natural period has not been modified by cutting out so much of the receiver cap. I should think that the records might have been taken by boring a small hole in it. The air cavity is likely to have some effect on the period. When sound is produced, energy must come from somewhere, but, as a rule, the efficiency of sound production is considered to be so low that the energy consumed is not given much attention. Just as an induction motor, clamped and at a standstill, will show different characteristics from a motor running, whether lightly loaded or heavily loaded, so will a telephone receiver show different electrical properties if the diaphragm is not allowed to move. It would be interesting to compare these records with others taken with the receiver held against the ear, in which case the " load " conditions would be those for which the apparatus is designed.

George D. Shepardson: There is one further point I want to call attention to in connection with the performance of the transmitters. In Fig. 6 the curve for the transmitter current is considerably flattened on one side; that is just what we should get if we had superimposed upon the fundamental wave a second wave having twice the frequency, but with the maximum corresponding with the maximum of the fundamental wave. That is just what is demanded in what is sometimes called the inverse theory of the transmitter, that is, the motion of the transmitter diaphragm which would be required in order to give a sine wave. That theory calls for a strong component of double frequency, and that is exactly what is shown in this experimental investigation, coming about from an entirely opposite direction. I think Mr. Anderegg was the first one who called attention to this in an article which appeared in *Telephony* in January, 1909, and his double frequency component, which he obtained mathematically, is exactly what is brought out in this oscillogram of the transmitter.

Frank Wenner: There is one point which I should like to call attention to, and that is that the motion of the diaphragm produces an e.m.f. in the circuit just as in any other dynamo electric machine the relative motion of a part of the magnetic field and the winding results in an induced or generated e.m.f. This e.m.f. is a back e.m.f. and at the resonating frequency of the diaphragm may amount to as much as 90 per cent of the impressed e.m.f.

This is a matter to which I wish merely to call your attention now, as I expect to take it up in the discussion of the vibration galvanometer, the telephone receiver being one form of vibration galvanometer.

George W. Pierce: This whole effect of the shifting of reactance and inductance is the reaction of the diaphragm on the coils and that is taken account of in our theoretical treatment.

I have no doubt the treatment is the same as for the vibration galvanometer, except for the lag in the iron, which will shift our change of resistance curve to where our change of induction curve ought to be if there were no magnetic lag; that is, the double angle of lag amounts to enough to almost interchange these two curves.

As to this amount of power, perhaps my illustrations were not clearly explained. I said that this 68 per cent increase of power occurred when we got at the resonant point of the diaphragm. That does not mean that we have the measure there of the energy of the moving diaphragm; it merely means that with a given e.m.f. we draw more power under one condition than under another condition. The excess of power drawn amounted to a considerable quantity, and no doubt a good deal of it went into sound and energy radiation from the diaphragm, a part of which is not sound. The experiments were made with 0.3 of a volt in the telephone circuit, *i. e.*, under conditions which were somewhere near normal. The strength of the current in the telephone varies with the frequency, but it is in the neighborhood of one milliampere.

This reaction of the absorption of the sound upon the sounding body is a matter that Professor Sabine, at the physical laboratory, of Harvard, has emphasized and pointed out to me by means of an experiment of that kind. He had a tuning fork electrically driven in a room and measured the energy of sound all over the room, everywhere, and integrated it so that he got the total amount of energy in the room. He then put felt, which is an absorber of sound, in the room, with the intention of reducing the sound and measuring it again. He measured it again, and he had more energy than before. Although the felt absorbed a lot of energy, there was more energy than before. The explanation was that, putting the felt in the room shifted the wave zones in the room. He set his tuning fork at a constant amplitude, but the power drawn electrically happened to be increased by the shift of waves due to the introduction of the felt.

On the question of the absorption of energy by an observer, Professor Sabine has measured the absorption of energy by a person—that is, he got the energy in the room, and measured it, and then got the energy absorbed per person. It is interesting that he found that a woman absorbs more sound than a man, the difference being due to the difference in the character and amount of clothing of the woman and the man.

John B. Whitehead: Referring to the explanation for the "dimple" in the diaphragm curves. Although I could not follow the first speaker very closely, I understand his suggestion is that the dimple was caused by the actual killing of the flux of the magnet itself, yet in the further progress of his remarks, he says that so far as he has been able to observe the total flux of the exciting magnet of the diaphragm changes very little throughout the range of operation due to the first current in any event.

George D. Shepardson: I distinguished between the ordinary operation of the receiver with the ordinary current, but in this case we have an extra current.

John B. Whitehead: That may be true, and is certainly a very interesting suggestion.

As to the relation of frequency to pitch, Mr. Flowers explained that, I believe. It is quite obvious that if we depend upon the natural frequency of vibration of the diaphragm for telephonic communication it is, therefore, desirable to have the peak spread out as far as it possibly can be, and as high up as possible toward the peak of the curve itself. So that, if I understand the question correctly, I should think we would aim to get a diaphragm with resonance curve broad at its base, rather than extremely narrow, such as the one that Professor Pierce has described.

I think that great difficulty would be met with in attempting to polish the surface of the diaphragm itself in order to use it as a mirror for reflecting spots of light. The definition on the plate resulting from a reflection from the tiny mirror is really got by the size of the mirror itself. All the light reflected from the mirror itself goes to the plate, and the polishing of the whole surface would, lead to a good deal of difficulty, diffused light spoiling the definition.

As to the thickness of the diaphragm, that would be an interesting line of investigation. Doubtless something has been done in this direction but so far as we know no results have been published.

As to the cutting out of the receiver cap, it is practically impossible to carry out any very extensive investigation of this kind without removing the receiver cap. We did nothing to check the influence upon the vibrations of the removal of the cap, but I do not believe, from the progress of the experiments, and from the absence of any evidence of an upsetting of any of the results, that it is an important factor.

It is proper in closing to state that the bulk of the work involved in the preparation of this paper was done by Dr. Meyer, in our laboratory, at Johns Hopkins University.

Charles F. Meyer: The explanation of Mr. Shepardson regarding the "dimple" in the curve obtained at 232$\sim$, for a range of 21.8×10^{-4} radians, seems very plausible. His explanation is corroborated by an examination of the curve at 1292$\sim$, for a range of 9.8×10^{-4} radians, which also shows a slight dimple. It will be observed that the values of the current corresponding to these two photographs were 68.0 and 61.1 milliamperes, and for no other records did the current have such high values. It would therefore seem as though the "dimple" were due to the high value of the current.

In setting down the equations (**2**) and (**3**), page 1027, it was not desired to convey the idea that the current in the coils of the receiver actually changes the induction in the permanent magnet, for there is no reason to believe this. There is a certain amount of induction present due to the permanent magnet,

and there is a variable induction, due to the current, superimposed on this. Equations (**2**) and (**3**) hold good independently of how far back into the pole pieces the variation in the induction extends.

The observation of Mr. Pierce upon the variation of power consumed by the telephone, accompanying a variation of the system of standing waves in the room, is very interesting. He did not state the proportionate magnitude of the change in power. In the present investigation no effect of the standing waves upon the amplitude was observed. The photographs were all obtained with the experimenter in one position, which was necessary for manipulating the apparatus, but no variation in amplitude due to walking around the room was visually observed. It is thought that a variation of ten per cent could not have escaped detection.

It was questioned as to how far the photographs might be relied upon to give the phase relation existing between the exciting current and the motion of the diaphragm. There was no attempt made to adjust the apparatus so that reliable measurements might be made, but the photographs give a general idea of the phase relation. According to the ordinary mechanical theory of forced vibrations the force and the vibration ought to be in phase when the frequency is low compared to the natural frequency of the system. As resonance is approached the phase of the vibration begins to fall behind and when the resonance has been well passed the vibration lags half a period behind the impressed force. In the present case the impressed force is that due to the magnetization, which lags somewhat behind the current, the amount of lag being small for low frequencies and increasing with the frequency. The vibration of the diaphragm ought, therefore, to be practically in phase with the current at the very low frequencies, then fall gradually behind as the frequency is raised, and when the resonance point has been well passed it ought to lag over half a period behind the current. Close scrutiny of the photographic reproductions of Figs. 3 and 4 will show that the vibrations are in phase for the low frequencies, and that the vibration falls behind as resonance is approached. The curve for 1292$\sim$, to which attention was called by Mr. Taylor, is beyond the resonance point. It seems to lag about half a period behind the current. The lag between the magnetization and the motion should, at this frequency, be almost half a period, and the real lag between current and vibration is probably more than half a period. The fact that the photograph shows only half a period may be due to lack of adjustment. The adjustment would have to be quite good in order to record the phases for the high frequencies with accuracy.

In answer to the question of Mr. Flowers it may be said that, before the small mirror was resorted to, attempts were made to reflect the light directly from portions of the diaphragm by silvering them, but even very small areas of the diaphragm are not optically true, and will not give a good image.

DISCUSSION ON "A TUBULAR ELECTRODYNAMOMETER FOR HEAVY CURRENTS" (AGNEW), "MEASUREMENT OF ALTERNATING CURRENT OF LOW VALUE" (NEWMAN), "TO MEASURE AN ALTERNATING-CURRENT RESISTANCE AND COMPARE IT WITH THE DIRECT-CURRENT RESISTANCE" (NORTHRUP), BOSTON, MASS., JUNE 28, 1912. (SEE PROCEEDINGS FOR JUNE AND JULY, 1912.)

(Subject to final revision for the Transactions.)

W. H. Pratt: Dr. Agnew's paper tells about the usual procedures in making a wattmeter for high current measurements, by stranding the conductor. Now, stranding the conductor must necssarily be done in a very careful manner, otherwise troubles will be encountered, but it performs two functions; it prevents the formation of eddy currents due to the field of the current coil itself, and it also prevents the formation of eddy currents due to induction from the moving coil. In an instrument in which you are going to get the highest possible sensibility it would seem that this should be taken account of. I see no reference to this in the paper.

In a discussion of the paper presented by Sharp and Crawford, at the Jefferson meeting of the Institute, in 1910, I gave a brief description of a reflecting dynamometer which we constructed some two and a half years ago for doing substantially the same work that the instrument described here is intended for. The two instruments differ in this way: The instrument described in Dr. Agnew's paper is evidently an attempt at making an instrument of which, from its geometrical constants, the accuracy characteristics can be determined. The instrument which we constructed was an instrument so designed that we were able to compare its performance directly with instruments of very small capacity in order to determine the limits of its accuracy. The instrument that we constructed, I think, is much more flexible than the one here described, because we can use it with the highest kind of accuracy in currents as low as 50 or 25, or even 10 amperes, and then can immediately go to 2000 amperes capacity. The heating of the conductor is negligible in any case.

The limits of accuracy of this type of instrument would seem to depend fully as much on the character of the suspension as on the other characteristics, and I am very much surprised at the statement that one-half of one-tenth per cent is thought possible, although one-tenth of one per cent certainly is definitely possible with the instrument that we worked with.

J. D. Ball: In reference to the paper "Measurements of Alternating Current of Low Value," mention is made of the use of a portable wattmeter as an ammeter by which Fig. 5 was derived.

This arrangement is of considerable value for measuring low currents, below the range of the portable alternating-current ammeters. An ordinary portable wattmeter with full field utilizes in the moving coil about 0.04 amperes for full scale

deflection. Separately exciting the field coil to the full rating, and passing the current to be measured through the moving system, gives an ammeter scale of 0 to 0.04, which is considerably better than an ordinary alternating-current portable ammeter, having the advantage of a uniform scale, instead of a scale of squares. When the current is smaller than can readily be measured by this means, the reflecting dynamometer is, of course, the correct instrument to use.

It is often the case that measurements of this kind are desired, and there is no phase shifter convenient. In such an event, good results may be obtained by the use of resistance and reactance in series with the separately excited coils and "juggling" until maximum reading is obtained.

When using the phase shifter, instead of obtaining a maximum deflection, it is perhaps more satisfactory to obtain zero deflection and to read the ammeter after a phase shift of 90 degrees.

It also happens that small currents are to be measured when the circuit is non-inductive, or the phase relations are definitely known, in which cases the separately excited wattmeter may be used without phase shifter or resistance and reactance in circuit.

Small voltages may be measured by the same general method, by exciting the current coils of a reflecting dynamometer and connecting on the moving coils.

Frank Wenner: Dr. Agnew asked me to make a few remarks in regard to his paper, and particularly in reference to a change which has been made since the paper was sent in. In the paper mention is made of the fact that the clamping of heavy lugs in making connections with the instrument had sprung the inner tube in such a way as to throw the arrangement out of symmetry, and that later the end terminals were clamped to prevent this. It was found very difficult to always prevent a slight amount of springing in connecting very heavy leads, so a change has been made. A slight flexibility is secured by cutting a circle 10 cm. in diameter from the outside copper slab which serves as a current terminal. The inside tube passes centrally through this 10-cm. disk of copper, and the latter fits into the hole in the copper slab from which it was cut, the electrical connection being obtained by amalgamating the joint. This gives the desired flexibility.

M. G. Lloyd: In connection with the measurement of very small alternating currents, it may be of interest to mention another instrument for that purpose, known as the thermo-ammeter, which has some particular characteristics which make it valuable for that purpose. Besides being a very sensitive instrument, it can be constructed without appreciable inductance, if necessary, and that is particularly valuable in many classes of high-frequency work, such as wireless telegraphy. The thermo-ammeter has a heating element which is in the main circuit. The heat developed in this resistor is applied by radiation to a small thermo-couple which is in the moving-coil circuit

of an ordinary d'Arsonval movement. You consequently get the characteristics of the direct-current instrument in the indicating part and have all the advantages of the hot-wire instrument in the energy producing or actuating part of the instrument. The great difficulty which I found with such an instrument, however, was the extreme slowness of the action. I think, perhaps, that could be improved by a better design; but it had that feature, which is to some extent common, perhaps, to all hot-wire or heating-element instruments.

In using a dynamometer, of course, great gain can be made by having an auxiliary current in the field, as the author has pointed out in this paper. The great disadvantage comes in in the case of wave distortion, which is always found, of course, in the use of coils containing iron. It occurs to me that the instrument might be used to great advantage in that case, by putting a similar coil in the field circuit. By using iron of about the same quality and saturated to about the same amount with flux, the wave distortion might be made approximately the same, and the instrument might then be used for that purpose. As the author has shown, it can hardly be so used under the conditions which he described.

It seems to me a word of appreciation of Dr. Agnew's work would be in order here. This dynamometer for heavy currents which he has designed seems to have eliminated all the ordinary sources of trouble in a dynamometer for such extremely high current. He has covered all the heretofore practical objections in the design and use of such an instrument, and it looks as though he had really solved the problem of the measuring of large currents.

Taylor Reed: With reference to Dr. Northrup's paper, he has indicated the measurement of alternating-current resistance, to use his term, to a considerable degree of refinement; in fact, to a greater degree of refinement than is necessary for most measures at commercial frequencies. Dr. Northrup speaks in particular of the unsteadiness of the circuit, and the difficulties arising from that, and he uses a very quick switch thrown back and forward, which, of course, eliminates nearly all of the error. In making similar measurements I have sometimes found it convenient, where two dynamometers are available, or where the measurements are being made with commercial instruments, like wattmeters, to use two, one connected to what you might call a self-calibrating resistance continually, and the other switching back and forward from the calibrating resistance to the unknown, or measured, resistance. Any violent fluctuation in the alternating-current source, to which the line may be very much subject, is readily shown, and in case the current is persistently unsteady can even be allowed for within moderate limits.

This subject of measuring conductors under alternating-current conditions is increasingly important. For instance, the

old discussion has gone on for a long time between copper and aluminum until it has come to seem as though there were no other conductors; whereas if we run over the elements, one after the other, we come to the fact, which is a very true one, although very ludicrous in its impracticability, that metallic sodium is a great deal cheaper than either of them. But, of course, the use of steel has been made necessary on account of its strength for long spans, copper-clad steel, in particular, having become of practical value. Also, considering the whole range of measurements at high-frequency alternating-current, it does seem as if some better term for this quantity which is measured than "alternating-current resistance" or "effective resistance" should be provided for general use.

A. L. Ellis: I have been very much interested in the tubular electro-dynamometer, reported by Dr. Agnew for measuring heavy currents, as I have met the necessity for a dynamometer of this type very frequently in my work. I have also used the water-cooled dynamometer referred to by Mr. Pratt and can testify to its accuracy.

There is one point that seems difficult to overcome in the tubular dynamometer and that is the distribution of the current through the tubes and the location of the tubes to bring everything coaxial, and maintain this condition.

In case of the water-cooled dynamometer, such disturbances do not exist, because the current terminals, themselves, are two heavy copper bars that can be placed one directly over the other, with sufficient insulation between them, and securely bolted to the base, making a rigid construction. Attaching the leads does not disturb the location of any of the parts affecting constant of instrument to an observable extent. The tube forming the field coils of the dynamometer are attached to the further end of the heavy copper bars. The turns of the current coil can be so arranged that the astatic moving coils can be readily removed from the field without disassembling. The great difficulty with all of these instruments is the suspension. If we could only get rid of this suspension, we would get rid of practically all the trouble in connection with the water-cooled dynamometer. There is one other point in connection with the water-cooled dynamometer that must be borne in mind, and that is, you must be sure iron does not get into the pipe forming the current coils. Iron will sometimes get into the circulating water from the iron service pipes, but this is readily overcome by passing the water through a glass vessel, used as a settling chamber for the circulating water.

Edward B. Rosa: One very great advantage of the tubular dynamometer that has not been mentioned is the fact that there is such a small stray field. The magnetic field is between the tubes, and there will be absolutely no stray field, if the tubes are long enough. There is, of course, some around the end, but the stray field at those places is extremely small. With an

electrodynamometer using coils of such character that the magnetic field extends a considerable distance from the instrument, errors may be introduced due to the presence of metallic masses in the neighborhood of the instrument or in the parts of the instrument. In the case of a dynamometer for measuring heavy currents, such as several thousand amperes, the stray field may be very considerable. In the tubular dynamometer, however, the magnetic field is almost completely included between the inner and outer tubes, and this is a very great practical advantage. This instrument has been thoroughly investigated, and there is no serious difficulty in respect to the centering of the tube. Fortunately, there is a definite test that can be applied to show that the current is symmetrically distributed.

L. T. Robinson: With regard to the measurement of small alternating currents, I think I might bring out one point quite clearly. We have three things which have been referred to in the discussion: the series-connected dynamometer, the thermal instrument in which substantially a D'Arsonval galvanometer is used on the thermo-couple, and the separately excited dynamometer, which is, of course, as has been mentioned, subject to some errors. The conditions as to sensitiveness, etc., that can be met with these instruments do not conflict. The series dynamometer can be used up to a certain point. After that we can use the thermal instrument, and away beyond that in sensibility, as I have found it in my work, is the separately excited dynamometer.

P. G. Agnew: In regard to the tubular dynamometer, Dr. Wenner has already mentioned the fact that a somewhat flexible connection to the inside tube has been secured by cutting one of the heavy copper slabs serving as current terminals and using an amalgamated joint.

Mr. Pratt has raised the question whether there may not be errors due to eddy currents in the copper tubes caused by current in the moving coil. At commercial frequencies no error whatever could be detected due to this cause. Even at 900 cycles, with full rated current in the moving coil and the field system short-circuited, the deflection does not exceed 0.1 mm. at any part of the scale.

The point made by Mr. Ellis in regard to iron impurities settling in the copper tubes which form the field system of his instrument is a very interesting one. The only part of our instrument which needs water cooling is the inside tube, and as there is no magnetic field inside this tube there is not much chance of the sediment causing trouble by becoming magnetized. However, it may be well to adopt the suggestion as an added precaution.

DISCUSSION ON "POTENTIAL TRANSFORMER TESTING" (CRAIGHEAD), AND "THE TESTING OF INSTRUMENT TRANSFORMERS" (AGNEW AND SILSBEE), BOSTON, MASS., JUNE 28, 1912. (SEE PROCEEDINGS FOR JUNE, 1912.)

(Subject to final revision for the Transactions).

Clayton H. Sharp: Regarding the last statement of Dr. Wenner, in his abstract of the paper by Messrs. Agnew and Silsbee, I find it rather surprising, inasmuch as the identical method for testing current transformers, with the exception of the vibration galvanometer detector, has been in use in our laboratory for two or three years, and a description of it was presented to the convention of the Institute three years ago, I think, at Frontenac. The method is absolutely identical with the one described in the TRANSACTIONS of the Institute, to which I refer, and we included a satisfactory detector, so that I do not see how in presenting a description of this method the statement could be made that no satisfactory detector was at hand. It was indicated at that time.

James R. Craighead: This paper on the testing of instrument transformers by Messrs. Agnew and Silsbee has brought forward the vibration galvanometer as a new device for use as a detector of small voltages on alternating-current circuits. A few points of comparison with the separately excited dynamometer may be worth consideration. First, in regard to the matter of sensitivity, we find that Mr. Agnew's galvanometer at 25 cycles gives a deflection of 0.5 mm. at a scale distance of one meter for one microvolt, or about 1.5 microamperes. The dynamometer which we are using for similar work requires about 4 microvolts or 0.1 microampere for the same deflection. This sensitivity can be considerably increased by simple changes, but has been found sufficient for the purpose.

Convenience. The vibration galvanometer must be adjusted by a change of the length and tension of the suspension or by adding weights for each frequency. This would involve much handling of delicate parts and consequent trouble if applied to commercial testing where change of frequency is made at short intervals. Also, reading to a zero with return in the same direction, presents a little more practical difficulty than reading a zero when the indicator passes through instead of to the point.

On the other hand, the separately excited dynamometer requires a phase-shifting transformer and a polyphase supply. A shift of phase without the polyphase supply is not difficult to arrange, but is much less convenient and in general less accurate than the polyphase method. The same adjustment of the dynamometer is correct for all frequencies. The reading is through a zero so that there is never a doubt in which direction to change the adjustment in finding a balance.

The use of condensers and reactance in connection with the resistances of a potential transformer outfit involves difficulties of commercial handling. Ordinary condensers are unsatis-

factory apparatus where permanent accuracy is required. Wherever a considerable amount of testing is to be done, this consideration alone may offset the advantage of using only one observer in phase-angle tests on potential transformers; especially as the time required for adjustment of resistance, reactance and condensers would undoubtedly diminish the actual gain. The condenser-reactance combination, which does not make a satisfactory phase-shifting arrangement even for exciting a dynamometer, is here made a part of the measurement circuit.

In general, the gain in using the vibration galvanometer appears to be the elimination of the polyphase circuit and phase-shifting transformer, and, in comparison with some other methods, of one observer. The loss is in the added complication of the instrument, the probable increase of time spent in repairs and adjustment, and the difficulties involved in shifting the phase of the measured voltage by capacity and reactance.

Edward B. Rosa: This discussion brings out pretty clearly that one cannot generalize and say that a given method is better than some other method, for a series of reasons, without going further and specifying the circumstances under which they are to be used. It may appear very difficult for one man, with certain routine surroundings, to use, for example, mutual inductances and condensers, whereas another man, having them at hand, may find them much more convenient than a polyphase source of power and phase-shifting devices or something else. The truth in this case is, that in one laboratory one method has been found to be much more convenient, and in another laboratory the other method is much more convenient. The writer of this paper, from his standpoint and training, thinks this is a very distinct improvement over previous practise, for the reasons he specifies; nevertheless another method may be much preferred in other surroundings by other experimenters.

L. T. Robinson: I would like to endorse that view fully. The advantage of such papers and such discussions as this is to bring out these facts, and there is everything to be gained by the one man knowing the point of view of the other man. I feel very sure that all of us who have been working along the line referred to appreciate the fact that perhaps unconsciously, but nevertheless quite truly, we have adopted a great many of the methods of other laboratories until there is more similarity than there was, at least in the test methods that are used. I know at the Frontenac meeting, three years ago, I had some very definite ideas myself on the subject, but they have become somewhat modified, although we hold to substantially the same practise as was described then.

Clayton H. Sharp: I want to say a word or two about the advantages and convenience of a synchronous reversing key or rectifier in measurements, not only of current and voltage transformers, but in some other alternating-current measurements as well. With the synchronous reversing key you can

use the direct-current galvanometer, you can use as sensitive a galvanometer as you want, although beyond a certain point other troubles come in which will prevent the use of the highest sensitivity.

This detector in transformer testing has the additional advantage that it is selective of the resistance and the reactive components in the e.m.f. In testing a transformer two operations are gone through with: First, the key is set so that it reverses in phase with the resistance drop from one shunt to the other. The deflection is then brought to zero. The brush holder is then shifted through 90 deg., becoming in phase with the reactive drop, and the mutual inductance is then shifted until the deflection comes to zero. These two adjustments are made separately and not simultaneously, and they do not get in each other's way. The whole operation is performed in a moment with a high degree of certainty, whereas in the vibration galvanometer you have an instrument which does not differentiate and a double adjustment is necessary. With practise, however, it may become easy, but there is still an advantage in the use of the other system. The synchronous reversing key can be readily used in measurements of inductance or capacity by the ordinary bridge methods, and it has the same advantages, that you can separate the resistance drop from the reactive drop. It has worked out as a very convenient and very sensitive and good instrument in alternating-current laboratory work.

L. T. Robinson: I think Dr. Sharp's remarks bring out Dr. Rosa's point to the fullest value. I started first with the reversing commutator and direct-current galvanometer, and it did not suit me very well. We then took up the separately excited dynamometer. On the contrary, Dr. Sharp got a reversing commutator that went a little better than ours went, and it has remained his method. The Bureau of Standards has found the vibration galvanometer useful. I have never tried one. We bought some, and put them up in the cases, and they are there yet, but we never have had time to test them out and see what they would do. Therefore, it is only fair to say that ideas along these lines should be tempered with the influence of surrounding circumstances properly considered.

Frederick Bedell: A word on the question of the synchronous commutator and the non-synchronous commutator—as Dr. Sharp has pointed out, with the synchronous commutator various adjustments are made which have certain points of advantage in manipulation and which make it possible to determine the phase angle as well as the amplitude of the quantity measured. If the commutator is driven by a motor that is just off from synchronism, none of these adjustments are necessary, and one's attention is free from other things in connection with the test. The galvanometer will then have beats and the deflection will rise to a maximum and fall; the deflection may be reduced to a minimum or to zero, thus giving a very sensitive zero instrument.

Edward B. Rosa: I would like to say something in defense of, or rather in justification of the vibration galvanometer. We have used the synchronous commutator with a direct-current galvanometer at the Bureau of Standards. Years ago we undertook to make refined measurements of certain kinds with that combination, but while the sensitivity is high the sources of error, we found, were serious, the commutator being a serious disturbance. We have had most satisfactory results with the vibration galvanometers, and it is for that reason that we are using them in several of our laboratories. The fact that the vibration galvanometer, attuned to the frequency of the current, practically ignores the harmonics, is a very great advantage in much of the testing. The sensitivity is so small for harmonics, as compared with that of the fundamental, that it has a very great advantage over the other style of instrument; and as to being obliged to make two adjustments at once, or not knowing, from the fact that the deflection is both sides of zero, which kind of adjustment to make, I can assure you a little experience makes that difficulty seem very much smaller than it appears at first sight.

We have used the vibration galvanometer, now, for ten years, and have a good many of them of different types in service, using them for very many purposes; we have also used the other styles of indicating instruments, so that we can speak from experience with both instruments.

W. W. Crawford: In regard to Mr. Agnew's paper on the testing of instrument transformers, I noted that Mr. Agnew states that he considers the method of connection which he has used, that is, introducing a resistance in the secondary circuit of the current transformer, with a mutual inductance for balancing phase displacement, is the best method that can be used. I believe I can verify that statement from practical sources, because we used the method some time back and we found it very satisfactory. We did not use the vibration galvanometers in connection with it, but we used, as I presume Dr. Sharp has already pointed out, a synchronous rectifier, which did not consist of a commutator with sliding contacts, which always give trouble. We used a rectifier consisting of a vibrating tongue, driven by a synchronous motor and a cam. The vibrating tongue carried platinum contacts which reversed the connections. The contact resistances were negligible so we were able to obtain the full sensitiveness of the direct-current galvanometer for alternating-current measurements. We were able to get the limits of sensitiveness which Mr. Agnew mentions with a synchronous motor of the type developed by Mr. Robinson, which could be carried in one coat pocket, and a portable galvanometer of the type made by R. W. Paul, of London, which could be carried in the other pocket. We could get a sensitiveness of one microampere per division, or 50 microvolts per division, the apparatus being entirely portable and independent of telescopes, reflecting scales, etc.

Frank Wenner: In regard to Mr. Craighead's statement concerning the sensitivity of the separately excited dynamometer, I need only say that the sensitivity of the galvanometer used is sufficient for all purposes. If a higher sensitivity were needed, I do not think there would be any difficulty in getting ten times the sensitivity indicated. Dr. Agnew simply stated he would rather have a galvanometer of this sensitivity than one of higher sensitivity.

In regard to the method Mr. Craighead described as compared with the method that Dr. Agnew is using, as I understand the situation, Dr. Agnew has used, for a period of four years, the identical method which Mr. Craighead has described, and I believe he considers the method he is now using as a decided improvement upon the former method.

In regard to Dr. Sharp's reference to the synchronous rectifier, Dr. Rosa has already pointed out some of the difficulties in regard to that. At the present time we have in the Bureau a synchronous rectifier, and have for some time been trying to make it operate satisfactorily. Dr. Burrows, who is working on that subject, has had difficulties, so has called upon the rest of us for suggestions. The various suggestions have been tried out, and at one time he made a visit to Dr. Sharp's laboratory to see if he could not get some more valuable suggestions there, but still the synchronous rectifier does not work satisfactorily.

P. G. Agnew and **F. B. Silsbee:** The discussion seems to have centered about the use of the vibration galvanometer as a detector and the question of what constitutes the most satisfactory detector. As has been very clearly stated by Dr. Rosa and Mr. Robinson, the answer to this question depends both upon the equipment and traditions of the laboratory and upon the training and experience of the observers. Certainly, Dr. Wenner did not intend to imply that the arrangement used by Dr. Sharp and Mr. Crawford of a mutual inductance with a rotating commutator and d-c. galvanometer as detector was an unsatisfactory one. Probably no one would claim that any of the detecting devices which have been used in the work is ideal, whether he is using a rotating commutator, a dynamometer, a vibration galvanometer, or, as has been used at the Physikalisch-Technische Reichsanstalt, an electrostatic instrument. Most of the instrument transformer testing at the Bureau of Standards during the last four years has been done by a dynamometer method very similar to that used by Mr. Craighead. However, it was always felt that a self-contained detector would be decidedly preferable. Both ratio and phase angle are determined by a single balance, and the accuracy does not depend upon any subsidiary or external adjustment, and no quadrature current is drawn from the network. This surely minimizes the chances of error. The condensers or inductances are used to shift the phase only by the small angle of the transformer, and the accuracy and permanency of such devices is far greater than that required by the precision which is desirable in phase angle measurements.

A point which has been entirely overlooked in the discussion is that the volt sensitivity is the essential consideration in current transformer work, while the current sensitivity is practically immaterial. In the case of potential transformers the reverse is true, but there is no difficulty in obtaining the requisite current sensitivity. Practically any commercial vibration galvanometer is sufficiently sensitive. In fact too sensitive a detector is undesirable, as it is likely to allow errors to enter from extraneous sources. The galvanometer described was designed to give a high volt-sensitivity and a low current-sensitivity.

It should be noted in this connection that a vibration galvanometer is analogous to a motor and the volt sensitivity cannot be obtained directly by multiplying the current sensitivity by the resistance, but account must be taken of the back e.m.f., as is pointed out by Dr. Wenner in a paper presented at this convention. He cites a case in which the back e.m.f. was approximately 40 times the $I R$ drop. Our galvanometer was designed to give a back e.m.f. approximately equal to the $I R$ drop, or a current sensitivity twice the value computed by Mr. Craighead.

DISCUSSION ON "INDUCTION TYPE INDICATING INSTRUMENTS" (MACGAHAN),
"COMPENSATING WATTMETERS" (ELLIS),
"HOT-WIRE INSTRUMENTS" (PIERCE AND TRESSLER), AND
"RESONANT CIRCUIT FREQUENCY INDICATOR (PRATT AND PRICE), BOSTON, MASS., JUNE 28, 1912. (SEE PROCEEDINGS FOR JUNE, 1912.)

(Subject to final revision for the Transactions)

F. P. Cox: Taking up the paper on hot-wire instruments first, it seems to me that there are limits to the use of this instrument, and yet there are occasions and circumstances where this particular type of instrument is better suited than any other type. For the measurement of low voltages, and particularly for the measurement of circuits of high frequency, I think we must all agree that it has no peer. But beyond those particular fields, it seems to me that its usefulness is rather limited, and limited, indeed, by the very reason that Mr. Pierce mentions, its high energy loss, which, for the 2000 ampere meter mentioned for the voltage given would come to 600 watts, which would be quite out of all reason. I would also mention, not from my personal experience, but a statement that I have very direct from some wireless people, that when you use it on the very high frequencies, it is desirable to use an air transformer rather than a shunt. I cannot give you any figures at all on that, but Mr. Price, who was with Fessenden, at Brant Rock, had very considerable experience with it, and strongly recommended the use of air transformers, in place of shunts, for high frequency.

So far as maintaining accuracy is concerned, the table that is given in the paper leaves little to be desired in this or even in any other type of instrument. It is well within the limits you would normally expect to find in the calibration of an instrument over a period of years, but I do not feel that this instrument will ever have a field except for service under the conditions for which it is particularly suited. I do not think it can "come back." That is almost too much to expect.

In regard to the induction type of instrument, I feel that here too, we have an instrument of exceedingly valuable characteristics for certain fields, but of decided limitations for other fields, which willl prevent it from "coming back." The long scale, which is inherent in the type, is a desirable feature, but we must not neglect to take into account that what we want to know is the current in the circuit, that if you can read an instrument beyond its limits of accuracy, or if you have an instrument which has an error greater than its reading capacity, you equally get into trouble. What you want is an instrument which will give you, so far as you can read it, the combination of being readable and possessing an accuracy which will give the closest approximation to the actual condition of the circuit. The longer scale is characteristic, and in itself, if obtained without any sacrifice, is good.

In regard to the question of the light moving element, I do

not feel at all that a light moving element necessarily means a weak element. The small threads referred to are definite threads —it is all in proportion to the part you are using, and light weight does not mean that you necessarily have a weak part, or a part which is liable to be injured in operation and in service. It does mean that the average meterman cannot handle it. The delicate, light moving parts must be handled by human hands with great care and skill, and with much experience, but so far as their operation in the instrument is concerned, I do not feel that there is anything to be worried about in that respect; because the mass you are handling, the forces you are dealing with, are, after all, comparable with the lightness of weight which you have, and are not necessarily liable to give trouble. I fully agree that shielding is essential, that strong shielding, double shielding, is essential, where you can have it, and that the magnetic disturbances which you find in your circuit are the greatest things to look out for.

As to the black and white scale, I believe that is properly a question of illumination. For tunnel work, there can be no shadow of a doubt that the black scale with a white figure is superior. For other conditions of illumination that may not be true, and for certain conditions of illumination it certainly is not true, but after all you must adapt your scale to the conditions of illumination, and should not expect that the illustrations given in the paper will be a true representation of average conditions. There will be conditions of illuminations where you will get that, and as Mr. MacGahan says, the camera may be more accurate than the eye, but you are putting up your instrument to be used in connection with the eye, and not to be used in connection with the camera. Therefore, it seems to me, that we cannot say definitely that the white letter is better, or the black letter is better, but there will be conditions of service where one will be superior and different conditions where the other will be definitely superior.

W. H. Pratt: I will speak on the paper by Mr. MacGahan. This paper is entitled "Induction Type Indicating Instruments," but for the most part it deals with the ammeter. The switchboard instruments of particular importance are the ammeter, voltmeter and wattmeter, and their importance, I should say, is in the order of the voltmeter, the ammeter and the wattmeter, that is, it is absolutely certain that the voltmeter should be accurate, it is essential that the ammeter be accurate, so that you are sure you do not overload the machines and lines, and the wattmeter is of little use unless it is accurate. As I understand these various induction type instruments, the ammeter is the most easily susceptible of giving accuracy, the voltmeter comes second to the ammeter, and it is with difficulty that the wattmeter is made to perform its work. The performance of the indicating wattmeters, of course, must not be confused with that of the rotating watt-hour meter, in which

there are automatic compensations coming in, which would make a remark of this character entirely inapplicable. I am sure that a light weight moving element is to be trusted rather than a heavy weight moving element, where it is properly designed, because a greater amount of structural strength can be given to a light weight than a heavy weight element in proportion to the strains to which it will be subjected.

Albert F. Ganz: I should like to confirm the statement made by the previous speaker to the effect that it is highly desirable to have the moving system in an electrical measuring instrument as light as possible, because this means a small moment of inertia requiring only a light damper, and also correspondingly small wear on the jeweled bearings. It is, of course, true, as already stated, that a light movement is much more difficult to repair by the ordinary meter man, but on the other hand an instrument with a very light movable system is much less likely to get out of order. In regard to the hot-wire instrument, I ask whether the instrument has a zero temperature coefficient, so that a series multiplier can be used with it having a constant multiplying factor.

A. W. Pierce: It has; the hot wire used in the voltmeter has a zero temperature coil.

F. V. Magalhaes: I ask Mr. Pratt to mention the temperature coefficient of the instrument, and it would be interesting to know if he has the figures, what the temperature coefficient is, and whether any attempt is made to compensate for temperature error.

William J. Mowbray: Concerning the induction type of ammeter and the black scale, I would like to say that the black scale was tried by me in the original experiment on the rotating watt-hour meter. This was used in cellars where the light is usually very poor, and we found it to be a fact that with very low illumination the black scale and white division showed up better, so that I believe for very low illumination the black scale is the better.

I would ask Mr. MacGahan to tell us just how he gets rid of the temperature coefficient in his induction ammeter? We know that the aluminum moving element will change some 4 per cent in temperature for every 10 deg. cent. change in temperature, and still the curve shows very little error due to temperature, and I have no doubt Mr. MacGahan can explain to us simply just how he does it.

A. L. Ellis: There are two or three points in the paper by Mr. MacGahan that have not been touched on by the speakers. One is in reference to the electrostatic disturbance. There is no occasion for electrostatic disturbance, because the moving system can be put at the same potential as the surrounding apparatus, and the only source of trouble would be static charges on the glass caused by rubbing the glass, and that certainly is not the thing to do, as it will affect the instrument.

A little further on in the paper the statement is made: "Experience and tests have shown that 15 grams maximum is a safe limit for horizontal shafts in V sapphire jewels, and that a ratio of torque to weight of 0.15 is a satisfactory minimum, when torque is expressed in centimeter-grams, and weight in grams, in the case of switchboard meters." I would like to ask Mr. MacGahan what line of reasoning led to that conclusion? It would seem to me, from what experience I have had with jewels and pivots that it is vital that the moving system be made just as light as possible.

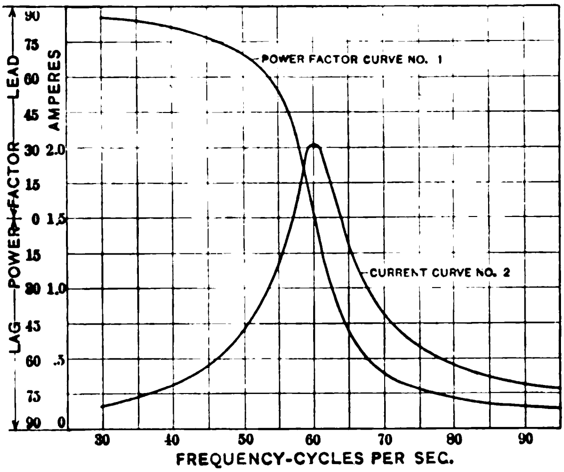
It is impossible to make a V pivot and bring it down to a theoretical point, so if we take a cross-section at the point of contact between the pivot and the jewel, the point of contact will not coincide with the axis of the pivot, but will bear at a considerable radius from this axis, therefore, the pivot will roll in the jewel when the pointer is deflected up scale, the pivot rolling up hill. The action of gravity tending to roll the pivot down hill is in opposition to the torque of the instrument and in the same direction as the torque of the control spring, tending to make the instrument read too low. If the instrument has been operating with considerable deflection and the current is reduced, the pointer tends to read too high for the same cause, as in this case the action of gravity acts in opposition to the torque of the control spring. This is a source of error difficult to reduce below an observable amount or even an objectionable amount, unless a very large ratio of torque to weight can be obtained. I think the error will be very pronounced even with the ratio mentioned of 1.5 (in gram-millimeters).

The moving system should be as light as possible for, although you can make the pivot out of hard steel, glass-hard in fact, and can use a sapphire as a jewel, which is very hard, yet a moving system of but very few grams weight is sufficient to deform the pivot and sapphire jewel. The pivot may be so hard and tough, that it can be driven into a piece of brass or a spring tempered steel scale, without distorting the regularity of its surface, but if this pivot formed the support for a moving system, as for instance the D'Arsonval type weighing only 1.5 grams, simply dropping it a few inches, will be sufficient to crush the steel pivot or to force the point to mushroom. The changed form of the pivot is substantially that of the jewel and, therefore, friction is increased to a noticeable amount, because a larger area is exposed to the jewel.

Paul M. Lincoln: I am particularly interested in the paper on Resonant Circuit Frequency Indicator, because some ten or twelve years ago I had an idea very similar to the one described. After I got the scheme pretty well worked out, a modification of the idea occurred to me depending on the same phenomenon, which seemed to me to be considerably better. That particular scheme was described in a paper which I prepared for the Institute and presented about eleven years ago at the Buffalo

convention. I want to say a word or two to show the principle upon which it rests. As we increase the frequency on a circuit containing inductance and capacity in series, we come to a certain frequency that will give a marked peak in the current flow. This is the frequency of resonance, and a curve showing the variation of current with frequency is shown in No. 2 of the accompanying figure. The fact that there is a marked peak of current at resonance is utilized to actuate the instrument described.

There is another phenomenon, which occurs at the same point, and it was on this other phenomenon that I based the instrument I speak of. At the same time that the current changes its value, the power factor of that current also changes its values very rapidly. This current leads when below resonant frequency and lags when above, while close to resonant frequency the power



factor changes very rapidly. This is shown in curve No. 1 of the accompanying figure. Hence, a standard power factor meter in a circuit that is adjusted for resonance at normal frequency makes an ideal frequency indicator. The sensitiveness of such an instrument may be varied as desired simply by varying the amount of resistance in the resonant circuit. All these points are brought out in my paper published in the 1901 PROCEEDINGS of the Institute.

F. H. Bowman: The hot instrument achieved a large measure of popularity some years ago, due, I think, to two causes. The instrument originally was imported from Germany, and on its way to America it did not lose its fine finish, which is characteristic of all fine instruments. Its fine finish was not lost when the instrument came to this country, and I ascribe the major portion

of its popularity to the fact of this fine finish and its very splendid appearance. The other cause to which I ascribe its popularity is the fact that it is interchangeable, as between alternating current and direct current. That last feature has lost much of its importance in the last few years, due to the increased knowledge of the art of measuring alternating current. The fact that it is interchangeable between alternating-current and direct-current is not so important as it was some years ago, and on that account the hot-wire instrument had a certain lapse in favor which is now about at an end, and I believe there is a new lease of life, we might say, for the hot-wire instrument on account of the wireless telegraph which, of course, is growing very largely.

In reading Mr. Pierce's paper the thing that appeals to me is the marvellous accuracy which is obtained in the use of the hot wire instruments in Mr. Pierce's hands, and I think I can state here, without danger of being accused of fulsomeness, that Mr. Pierce is a very skillful man in handling hot-wire instruments. People who read this paper will assume, naturally, that by the use of hot-wire instruments they will secure the same degree of accuracy which Mr. Pierce reports, or if they fail to do so, they will condemn the instrument. Hence the conclusions I draw are these: Where the hot wire instruments are used skilfully, by a skilful man, who is aware of the tricks of the hot-wire instruments, such a man will procure excellent results from them, whereas another man, who is less skilful in their use will get into more or less difficulty with them, and will be disappointed in the results obtained.

The question was brought up about the effect of the temperature coefficient in hot-wire instruments. We will take a voltmeter 0.03 in. in diameter, that is the smallest we can use. That wire is made with practically zero temperature coefficient, so the first thing is—the hot-wire instrument has a zero temperature coefficient. But this point I will make, and it may be new; the hot-wire instrument, although it has no general temperature coefficient, it has an apparent temperature coefficient that is of considerable magnitude, and can easily be determined; that is to say, although the wire in itself has no temperature error, when you put a load on it, and heat the hot wire up to a point where it expands, it increases in resistance, and although the specific resistance of it is still the same, the apparent resistance changes, due, I believe, to a decrease in the cross-section of the hot wire, on account of the heating. For high voltages, 150 volts, I call that high for hot wire, that is negligible on account of the considerable resistance in series with the hot wire, but as you drop down, and the series resistance becomes low in the hot-wire instrument, the errors increase in importance, and when you have a low-voltage instrument, five volts or three volts, the apparent temperature coefficient is something you have to take into account.

F. P. Cox: There is a point which has a bearing, not only on the types of instrument under discussion, but also on the

general instrument problem, and that is where Mr. MacGahan mentions the desirability of opening the scale at the top. I do not agree with him, not only as that point is applicable to induction types of instruments, but to any instrument. You have control of the scale of distribution. An ammeter put upon the circuit of a generator must take care of overloads, and that is rated at 100 per cent in excess of the capacity of the generator, and normally is working much below one-half of that. Therefore, within a certain limit as we have the scale at our disposal, it seems to me, we should not spend too much of our scale length in getting wide open divisions at that portion of the load which the instrument rarely meets and only for very short periods. Therefore, it seems to me that the equi-crescent scale is more suited to this purpose, or a scale which closes slightly at the upper portions, and remains open at those portions where the instrument is used nine hundred and ninety-nine times out of a thousand.

N. Monroe Hopkins: Are there any data on the weight in grams of the rotating member of the induction type meter as used?

Paul MacGahan: Referring to Mr. Mowbray's question: The method of compensating the ammeter for temperature changes is very simple. The windings consist, in fact, of a series transformer, wherein the secondary coil is wound on an electromagnet, the primary coil wound right over same, and the polepiece coils short-circuited across the secondary. As the temperature of the aluminum drum increases its resistance increases, tending to reduce the torque in the ratio of the temperature coefficient of the aluminum. At the same time, however, the resistance of the secondary winding which is partially or mostly copper, increases which is equivalent to introducing resistance in the secondary circuit of a series transformer which of course, increases the magnetic flux. The increased magnetic flux gives greater driving power, and exactly compensates for the increased resistance of the drum. This is explained, somewhat theoretically, in the paper itself.

As regards the relative accuracy of the voltmeter and the ammeter, it is true that the ammeter has a greater accuracy than is possible with the voltmeter. This is, at the same time true with all other principles of operation, so that it cannot be said to be exclusively a feature of the induction meter.

With regard to the errors of the wattmeters, the wattmeters as developed have temperature and frequency errors closely approximating those of the voltmeter and the ammeter. As stated by Mr. Pratt accuracy of slightly lower order than of the ammeters or voltmeters is permissible in a switchboard wattmeter.

Messrs. Pratt, Ellis and Cox express themselves very much in favor of a very light weight moving element for indicating meters. In this I concur only providing the lightness is not obtained at a

sacrifice of torque ratio and staunchness. As a comparison it may be pointed out that in a-c. watt-hour meter practise certain manufacturers have greatly favored a movement of 30 grams weight rather than one of 15 grams and have argued that the increase torque obtained thereby is an advantage. If a weight of 30 grams upon one jewel is considered satisfactory by them, for watt-hour meters, should not they consider a weight of 10 grams distributed between two jewels satisfactory in every respect for an indicating instrument? The average of three makes of moving iron instruments made in this country and abroad, shows a weight of two grams for the movement, with a torque of $^1/_{10}$ centimeter-gram; the induction type movement described by me weighs 10 grams, with a torque 28 times as great, which shows quite a predominance in favor of the induction type, with regard to ratio of torque to weight.

It has been pointed out on one or two occasions, that the weight, acting upon the theoretical point of contact on the jewel, results in a pressure of several hundred thousand pounds per square inch. This is surely an academic point, otherwise the jewel would give way on the slightest impact. As a matter of fact the bearings operate very satisfactorily.

As regards scale length in switchboard indicating instruments, the readability of the scale should be of a higher order of accuracy than that of the meter element itself. This is on account of the fact that readings are often required to be taken hurriedly from a distance, and thus the condition is different from that obtaining in portable instruments, where a close observation may be made and thus a scale no more accurate than the inherent accuracy of the mechanism, is permissible.

W. H. Pratt: There was a question asked as to temperature errors in the frequency indicator which I described, and I may say that there are three elements in this device whose temperature coefficients must be considered. There are the condensers, the reactances and the resistances, beside the mechanical parts. It is easily possible to make the mechanical structure so that there are no temperature errors introduced thereby. The errors due to change in resistance can be reduced to negligible quantities, because the resistance does not come in as a large factor, and what there is of it can be made to have a low temperature coefficient. The reactance can also be made to have an entirely negligible temperature coefficient, and by properly designing the condensers these also can be made to have zero temperature coefficient so that the instrument, as stated, has a temperature coefficient that is almost exactly zero. It is extremely small.

A. W. Pierce: The question has been asked whether the voltmeter has a zero temperature coefficient. The voltmeter has a small temperature coefficient, but any slight alteration in resistance that may arise, or any other change of drop in the wire is taken care of in the method of calibration, and automatically corrects itself when the instrument is calibrated.

It has also been stated that the results shown in the paper are those where extreme care was used. Personally, I had nothing to do with the checking of these instruments. This is the routine calibration of our standard as it was taken by men in the laboratory, most of whom have been there only a short time, and some of them less than two months, though they have been instructed in the care of hot-wire instruments and have been told something of their limitations.

John Gilmartin: (communicated after adjournment): It is very interesting to note how the many obstacles to an accurate induction type instrument have been met and skilfully overcome as is so ably shown in the paper on induction type meters. One characteristic of the induction type instrument not mentioned by Mr. MacGahan is that the torque developed on severe overloads is excessive and may shift or break the pointer.

A certain central station switchboard has the feeder panels equipped with induction type instruments and it has been found that circuit disturbances occur quite frequently that are severe enough to cause the pointers of the instruments to bend, and in some cases break off when the pointer hit the stop and in others to slip on the armature shaft and thus shift zero. Attempts to overcome these effects by improving the spring stop have been only partly successful.

A brief discussion of the characteristic action of the other types of instruments on overload is of value in bringing out the comparative effects.

The magnet vane and dynamometer type instruments have a limited scale movement, that is, the vanes or moving coils usually, as the load increases, move from a position across the field of the fixed coils to a position parallel to it after which there is no further torque no matter how excessive the overload. Such instruments, as is well known, usually have scales whose divisions become very small at both ends, that is, the torque per scale unit decreases rapidly as the pointer approaches the maximum scale point.

Induction type meters on the contrary, by reason of the rotating field principle, have a constantly increasing torque with load, and the divisions and torque per scale unit become larger at the maximum point of the scale. The pointer is not naturally limited in its length of throw as are the other types referred to; that is, if the stops were removed the moving part would rotate at a definite speed as an induction motor.

In a test made on a modern switchboard type induction ammeter it was found that if 300 per cent of full load current was thrown on the meter the pointer was thrown so hard against the stop as to cause it to shift its zero position. On the other hand 500 per cent of load thrown repeatedly on a magnetic vane instrument caused no zero shift. Both types of instruments had magnetic damping. The inferior results given by the induction meter on this test were not considered due in any sense to

poor design or workmanship, as both were excellent, but rather to the relatively tremendous overload torque inherent in the rotating field principle.

Paul McGahan: Referring to Mr. John Gilmartin's communication after adjournment, the effect of overload upon the pointers of induction meters is more severe than in other types, due to the increase in torque, but the movements can be made strong enough to withstand it.

Although trouble as stated appeared in certain cases, this can be said to be part of the development of the type, for the matter has been satisfactorily corrected. The ammeters described will withstand fifteen times full load current thrown on repeatedly without damage—in fact— the coils will burn out on overload before the pointer or other parts of the movement become damaged. This compares very favorably with the overload capacity of moving iron or moving coil meters. Although it is true that in moving iron vane instruments, the iron moves to a position parallel to the lines of force through the coil, this takes place only after an appreciable length of time, as the meters have inertia and dampening. The overload effect takes place instantly while the iron is still in its position of maximum torque and thus the result is that an enormous torque is developed the same as in induction instruments.

Discussion on "Measuring Stray Currents in Underground Pipes" (Hering), Boston, Mass., June 28, 1912. (See Proceedings for June, 1912.)

(Subject to final revision for the Transactions.)

Albert F. Ganz: In electrolysis surveys it is important to measure the currents flowing on pipes. The most common method used for this measurement is to treat part of the pipe length as a shunt, and to measure the drop across this shunt with a sensitive milli-voltmeter, and then to compute the current from the measured drop and from an *assumed* resistance of the included pipe length. The methods which Dr. Hering gives in his paper for measuring pipe currents involve essentially the *actual measurement* of the resistance of a length of pipe, which is part of a piping system. These methods are in fact special cases of a general method based on Kirchhoff's first law, namely, that the sum of the currents flowing towards a junction point is equal to those flowing away from the point. This principle has been used before for measuring pipe resistances, and is mentioned on page 67 of the American edition of Dr. Michalke's book on "Stray Currents from Electric Railways" published in 1906. For a number of years I have also used in special cases what is practically the last modification of the method described by Dr. Hering in the second paragraph of page 1156. In carrying out the method I have used the connections shown in Fig. 1 of this discussion.

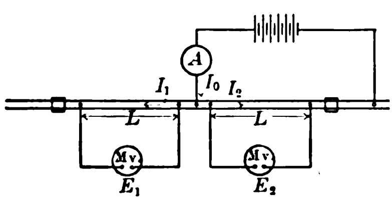


FIG. 1

The two millivoltmeters are similar and highly sensitive instruments, one scale division representing 0.1 millivolt. They are shunted across equal lengths of pipe, and a battery current is introduced in the middle, as shown in the diagram. I have found it convenient to use a battery current larger than the pipe current, so that the currents I_1 and I_2 flow in opposite directions. The two instruments are first read simultaneously with the battery circuit open, in which case the readings are due to the stray current on the pipe. If the readings are alike, which is generally the case, the two included shunts have the same resistance; if the readings are not alike, the two included shunts have resistances proportional to the readings. The battery circuit is then closed, and the ammeter and the two millivoltmeters are read simultaneously. If the two millivoltmeters previously read alike, the resistance of the pipe between contacts is

$$R = \frac{E_1 + E_2}{I_0}$$

Where trolley rails are accessible I have frequently dispensed with the battery, and have connected from the middle of the

pipe through an ammeter directly to the rails, thus drawing current from or to the pipe. The use of battery current has, however, the advantage of giving steadier readings.

I have used the above method for measuring the resistances of pipes and of lead cable sheaths in special cases. Such cases arise, for example, in long cable sheaths or in long individual pipe lines, where it is desirable to measure current flow simultaneously at two or more points for the purpose of determining the change of current between the points; where the changes are small the individual readings must be taken with considerable accuracy.

Stray currents on pipes fluctuate violently from moment to moment and also vary greatly during different periods of the day. Great accuracy in measuring stray currents is therefore generally unnecessary. This is particularly true in the case of pipes forming parts of interconnected networks, where the method of determining the flow to or from a pipe from simultaneous readings is not generally applicable, and where variations of 10 per cent or even 20 per cent would not be serious. For such cases it is abundantly accurate to measure the millivolt drop in a measured length of pipe, and divide this by the resistance of the included length of pipe, estimated from its known size and material.

I have found in the case of long individual pipe lines or long cable lines, that a fair estimate of stray current leaving or flowing to the pipe or cable sheath can only be obtained from a comparison of simultaneous 24-hour records of the current flow at successive points. These records can be obtained by means of suitable recording millivoltmeters.

Dr. Hering states, in the third paragraph of page 1154, that after he had completed a series of resistance measurements at many points over miles of a pipe line, he had found that the computed resistances per foot of pipe differed very greatly from each other. Upon examination, however, it was found that some portions of the pipe line had been laid with heavier pipe than others, and when a correction was made for this the results agreed very well. He concludes that this is a proof of the reliability of his method of measuring resistance. It seems to me, however, that it really proves that the method of estimating the resistance of a pipe from its dimensions is reasonably accurate.

I am convinced from my experience that in about 95 per cent of the cases met in practise, the method of measuring drop between two contacts on a pipe, and dividing this by the resistance of the included length of pipe estimated from its dimensions, is sufficiently accurate for practical purposes, and on account of its great simplicity it is to be preferred. I am prepared to admit that I have used, and am still using, this method for a great many pipe current measurements, and believe it is a perfectly satisfactory and practical method.

Where current flowing from or to a pipe is obtained from

simultaneous current measurements at two points, I have found it very necessary that the two instruments have the same period of vibration, as otherwise they will not fluctuate together, and the instantaneous readings cannot properly be compared.

Dr. Hering also states that he has devised a method of identifying pipe currents, consisting of simultaneously measuring drop along a pipe and drop along rails, and comparing the fluctuations in these curves of drop. I would like to say that I have used this method, but find it better to obtain simultaneous 24-hour records of the drop on a pipe and on the rails, and then to compare the characteristic variations of these drops. I have found it satisfactory to use a few feet of pipe and of rail for this purpose. I have also found where there is an extensive piping network, and where there are several individual rail lines, that the current on any one pipe may not fluctuate with the current in the neighboring rail, because the pipe is receiving current from a number of rail lines. The method of comparing the twenty-four hour records of drop on the pipe with the rail drop is therefore safer in such cases.

Dr. Hering also states that the ground current detector is academically interesting but could not be used because it disturbs the very conductor through which the current to be measured is flowing. I presume that he refers to the Haber earth ammeter. It is true that this earth ammeter is not satisfactory as a means of measuring the total current leaving a pipe. I have, however, found it exceedingly useful as a means of proving that stray current is actually leaving a pipe which is found corroded, and by using the earth ammeter with a recording instrument for identifying the source of the current leaving the pipe.

Edwin F. Northrup (by letter): In this paper Dr. Hering has made a valuable contribution to the literature of a class of electrical measurements which is commercially important. A word on the history of the development of these methods is not out of place. According to the writer's best knowledge (and he has informed himself with considerable pains), the original conception and original execution of the methods of measuring currents in underground pipes and the resistance of sections of such pipes as Dr. Hering describes in connection with Figs. 1 and 2 of the paper, belongs wholly to the author of the paper. The method, rather vaguely described on page 1157, intended as a modification for avoiding the difficulties which arise from the fluctuations of the currents in the pipes, was quite independently devised, fully worked out, generalized, and tested in the laboratory and in the field, by the writer of this communication. The present writer has tried no other method as he believes, thoroughly, both from theory and tests in laboratory and field, that it is the best method for the purpose, that it is quite general in application and is not at all deserving of the criticisms, made in the paper, beginning with the third paragraph of page 1158.

Its independent conception was undoubtedly stimulated by a full knowledge of what Dr. Hering had accomplished by the method described and shown in Fig. 1 of his paper. But the writer of this communication feels that he has added precision and generality to the methods which Dr. Hering has described. The importance of the subject is such that the writer thinks his viewpoint and additional contributions should be presented to the Institute for permanent record in full. What follows is taken from the writer's notes, which were prepared over one year ago.

Resistance Measurement of Closed Circuits. The problem is often presented in commercial practise of obtaining the resistance of a portion of a circuit which is closed upon itself and which may contain a source of current, either alternating or direct. If the circuit could be opened even momentarily the problem could be solved by well-known methods. But if the circuit

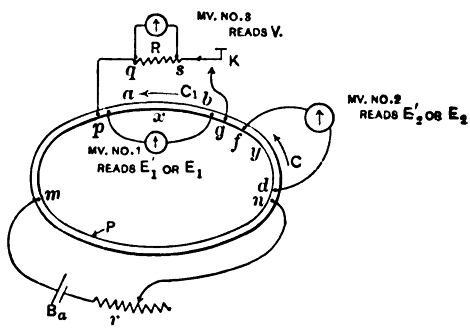


FIG. 2

cannot be opened, the problem is still solvable in more than one way. The following methods have been carefully tested out by the writer in practical cases, and have been found to give such satisfactory results as to warrant a detailed description.

We shall first consider a general method applicable to measuring the resistance of a section of a closed conductor loop, such as the rim of a cart-wheel, which may be assumed to have a cross-section which varies in an unknown way from one portion of its circumference to another. Referring to Fig. 2, we have the following dispositions of circuits and instruments.

P is a closed metallic circuit of medium or very low resistance which *cannot be opened*. It is required to determine the resistance x of a definite length of this closed circuit, as between two points a and b. For this there are required three deflection instruments which deflect proportionally to the current through them. The constants of these instruments need not be known but must be the *same* for all three. In the present application of the method

there is required one known resistance R provided with potential terminals. This resistance R should be chosen, for the best accuracy, of the same order of magnitude as the resistance x which is to be determined. A cell of storage battery and a rheostat r to adjust the current from the battery to a suitable value, are required, also a key K. The deflection instruments would ordinarily be millivoltmeters, though three galvanometers having the same constant could be used. Millivoltmeter No. 1 is joined to the potential terminals a, b, between which the resistance is x. Millivoltmeter No. 2 is joined to the potential terminals f, d, between which the resistance is y, and the terminals of millivoltmeter No. 3 are joined to the potential terminals q, s, between which the resistance is R, which is known. The current terminals of R are joined to the points p, g, of the loop, and in circuit with R is the key K. The cell of storage battery $B\,a$, which includes in its circuit the rheostat r, is joined to two points such as m and n, of the closed metallic circuit. This supplies to the system the current required for the measurement.

The procedure in making a measurement is as follows:

a. With the key K open, *read at the same moment* millivoltmeter No. 1 and call its deflection d_1' and millivoltmeter No. 2 and call its deflection d_2'.

b. With the key K closed *read simultaneously* the three deflection instruments. Call the deflection of millivoltmeter No. 1, d_1, of millivoltmeter No. 2, d_2, and of millivoltmeter No. 3, D.

Then, in case (a),

$$\frac{x}{y} = \frac{d_1'}{d_2'} \text{ which call } N;\ \text{then } x = N\,y \qquad (1)$$

In case (b), since the deflections D, d_1 and d_2 are proportional respectively to e.m.fs. V, E_1, and E_2, we have

$$E_1 = K\,d_1 = C_1\,x \qquad (2)$$

and

$$E_2 = K\,d_2 = C\,y \qquad (3)$$

Here K is a constant and C is the current through y, and C_1 is the current through x. We also have

$$C = C_1 + I, \text{ where } I \text{ is the current through } R.$$

But

$$I = \frac{V}{R} = \frac{K\,D}{R}, \text{ whence } C = C_1 + \frac{K\,D}{R} \qquad (4)$$

In the relations (1), (2), (3) and (4) we have the unknown

quantities x, y, C and C_1 and hence, there being but four unknown and four equations, both x and y can be determined.

We finally derive $x = \dfrac{d_2 N - d_1}{D} R$ (5)

and

$$y = \frac{d_2'}{d_1'} x \quad (6)$$

Equation (5) is obtained as follows:
From (3) and (4)

$$\frac{K d_2}{y} = C_1 + \frac{K D}{R} \quad (7)$$

From (2) and (7)

$$\frac{K d_1}{x} = \frac{K d_2}{y} - \frac{K D}{R}$$

or

$$\frac{d_1}{x} = \frac{d_2}{y} - \frac{D}{R} \quad (8)$$

Putting in (8) the value of y from (1), we obtain

$$\frac{d_1}{x} = \frac{d_2 N}{x} - \frac{D}{R} \quad (9)$$

and from (9) we find the value of x to be that given in (5).

The above method possesses four special merits: The circuit of the resistance being measured does not have to be opened; the resistance of no contact enters, and hence the contacts at points p, g, m, n and k need not be made with any special care, while the points a, b, f, d, q and s are merely potential points and contact at these places may be made with a sharp point or knife-edge pressed against the conductor; the constant of the deflection instruments need not be known, it being only necessary that all three instruments have the same constant; two instruments are read simultaneously in case (a) and the three instruments are read simultaneously in case (b), hence the current in the loop, P may be very variable, and accurate results still be obtained.

This method was tried by the writer, using a brass ring a little over one meter in circumference and of No. 0 B. and S., wire. The ring was placed over an open-core alternating-current electromagnet of very great size. By exciting the alternating-current magnet induced alternating currents were sent through

the ring. It was found that the readings of the three instruments, and hence the resistances measured, were in no wise affected by the presence of the alternating current induced in the ring, hence the method applies whether the closed loop is or is not carrying an alternating current.

In the above trial the actual readings observed and the results obtained were as follows:

$d_1 = 20.54$; $d_2 = 25.18$; $D = 18.51$; $R = 0.01$ ohm. The ratio of d_1' to d_2', or N, was 0.9940. From these readings the value obtained for x was, by equation (5),

$$x = \frac{25.18\ (0.994 - 20.54)}{18.51}\ 0.01 = 0.002425 \text{ ohm.}$$

The ring was afterward cut open and the resistance x was determined by an ordinary method, and found to be 0.002439 ohm. Hence the error in the measurement of the closed ring was 0.57 of 1 per cent.

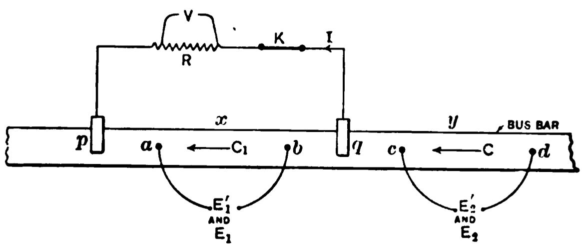


FIG. 3

This method has a useful application when applied to the determination of the resistance between two points in a d-c. busbar while this is carrying its current.

To Measure the Resistance between Two points on a Busbar. The arrangement to emplcy is represented in Fig. 3. The potential points a, b, and c, d, may be obtained by drilling and tapping small holes in the busbar and inserting in these holes small screws to which the terminals of the millivoltmeters may be secured. The terminals of the resistance R may be attached to the busbar at p and q by means of iron clamps, as the precision of the method is not affected by contact resistances at these places. The distances, between the point a and the clamp p, and the point b, and the clamp q, should be at least three times the width of the busbar. It is also desirable to have the clamps p and q make contact with the busbar across its entire width. The purpose of these two precautions is to insure that the stream lines of current are parallel with the busbar at the potenial points a and b. For the same reason the potential point c should

be as far to the right of q as the potential point b is to the left. The distance from c to d should be chosen about equal to the distance from a to b in order to bring the ratio N near unity.

If there is direct current in the busbar, supplied by the generator, then there is no necessity of introducing additional current from storage cells, as is required when measuring the resistance of a section of a loop as in the example above.

The standard resistance R should be supplied with potential points and should be not over ten times the resistance of the busbar between the clamps p and q. Greater accuracy will be obtained if this resistance is about equal to the resistance of the busbar between the clamps. Since the drop of potential over the resistance R is read to give the value of the current I, which flows in the branch circuit, one may substitute an ammeter for the resistance R and the millivoltmeter which reads the drop over this resistance. In this case, however, the other two deflection instruments must read, not in arbitrary units, but in volts or millivolts.

The procedure is the same as in the case of the ring, described above. Giving the symbols the meanings designated in Fig. 3, we have:

With the key K open,

$$\frac{x}{y} = \frac{E_1'}{E_2'} = N \qquad (1)$$

With the key K closed, we have, from readings taken simultaneously by three observers

$$E_1 = C_1\, x \qquad (2)$$

and

$$E_2 = C\, y \qquad (3)$$

We also have the relation

$$C = I + C_1 = \frac{V}{R} + C_1 \qquad (4)$$

From (1), (2), (3) and (4) we deduce, as in the case of the measurement of the resistance of a ring,

$$x = \frac{E_2\, N - E_1}{I} \qquad (5)$$

or

$$x = \frac{E_2 N - E_1}{V} R \qquad (6)$$

If equation (6) is used, E_1, E_2 and V can be multipled by the same constant, a, and hence the deflection instruments may be

calibrated in arbitary unit, provided the same arbitrary units are used for all three instruments.

The purpose to be fulfilled in finding the resistance between two points in the busbar is to enable the current in the busbar to be measured at any time by reading the drop of potential between the points with a millivoltmeter. A portion of the busbar is made in this manner to serve as a shunt for a millivoltmeter, which thus becomes an ammeter for reading the current in the busbar. As busbars are made of copper or aluminum, which have a large temperature coefficient, we have to consider to what extent, if any, their change in resistance with temperature will affect the precision with which the current may be read. Let Fig. 4 represent an arrangement to be employed.

Here, $B - B_1$ is a section of a busbar. We shall suppose that the resistance R_{20}, has been accurately obtained at 20 deg. cent., between the two points a and b, by the above method. The millivoltmeter MV is joined to the points a and b.

Let
$$r_T = r_{20}(1 + \alpha T) \qquad (1)$$

to be resistance of the millivoltmeter at T deg. cent. above 20 deg. cent. when r_{20} is its resistance at 20 deg. cent. and α is the temperature coefficient of its winding.

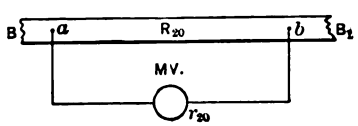


FIG. 4

Let
$$R_t = R_{20}(1 + \beta t) \qquad (2)$$

be the resistance between points a and b of the busbar at t deg. cent. above 20 deg. cent. when R_{20} is its resistance at 20 deg. cent. and β is the temperature coefficient of the material of the busbar.

The busbar may change in temperature both from changes in the temperature of the room and from the heating due to the current which it carries. The millivoltmeter MV can only change in temperature from changes in the temperature of the room. Hence, in general, the temperature T of the millivoltmeter will not be the same as the temperature t of the busbar.

We wish to determine the nature and magnitude of the errors produced by these temperature changes in reading the current. If I is the current in the busbar, the fall of potential from a to b, when the temperature of busbar is t, will be

$$E_t = I R_t \qquad (3)$$

The current through the millivoltmeter will be

$$C = \frac{E_t}{r_T} = K D \qquad (4)$$

where D is the deflection of the millivoltmeter and K is a constant. Hence

$$E_t = K\ D\ r_T \tag{5}$$

By equations (3) and (5),

$$I = K\ D\frac{r_T}{R_t} = K\ D\frac{r_{20}\ (1 + \alpha\ T)}{R_{20}\ (1 + \beta\ t)} \tag{6}$$

Since the busbar and the winding of the millivoltmeter are both of pure metal, as copper or aluminum, the temperature coefficients α and β would be practically the same and may be taken, approximately, as 0.004. Equation (6) can therefore be written.

$$I = \frac{K\ D\ r_{20}}{R_{20}} \times \frac{1 + 0.004\ T}{1 + 0.004\ t} \tag{7}$$

The error in the measurement of I is now seen to depend directly upon the amount by which the last term of equation (7) departs from unity. In the case of no heating, by the current, of the busbar above room temperature, (as would be very approximately realized for a loading of the busbar of 50 per cent full load or less) $t = T$, and there is no error, whatever the room temperature becomes. Now t can never be less than T, but may assume a value $T + \delta\ T$, where $\delta\ T$ represents the temperature of the busbar above the temperature of the air. In this case equation (7) becomes.

$$I = \frac{K\ Dr_{20}}{R_{20}} \times \frac{1 + 0.004\ T}{1 + 0.004\ T + 0.004\ \delta\ T} \tag{8}$$

As a rather extreme case we may take $T = 10$ deg. cent. above 20 deg. cent., and $\delta\ T = 5$ deg. cent. Then

$$\frac{1 + 0.004 \times 10}{1 + 0.004 \times 10 + 0.004 \times 5} = \frac{1.04}{1.06} = 0.981 +.$$

Thus the true value of the current would be, in this case, about two per cent less than one would read it upon the millivoltmeter.

The following estimate shows that the fall of potential in a busbar is large enough to apply the above method of measuring the current in it; though the writer has not had an opportunity of putting the method into practice as was done in the other cases here described. The resistance of 100 per cent conductivity copper at 20 deg. cent is 67.7×10^{-8} ohm per linear inch

(25. 4 mm.) per sq. in (6.45 sq. cm.) of cross-section. It is good practise to allow 1000 amperes per sq. in. of cross-section of copper conductor. Then, with 1000 amperes to the sq. in. of cross-section, the drop of potential per linear in. becomes $10^3 \times 67.7 \times 10^{-8} = 0.677 \times 10^{-3}$ volt, or 0.677 millivolt per per linear inch. If the full scale reading of the millivoltmeter is 20 millivolts, the distance between the potential points a and b (Fig. 4) would need to be $\frac{20}{0.677} = 29.2 +$ in.

This length of busbar, to be used for the purpose of a shunt, could be obtained behind most any switchboard, and it is probable that a shunt for the millivoltmeter of this character would serve quite as well and perhaps be superior to the shunts ordinarily used. For these latter have a very low temperature coefficient and changes in the temperature of the room will increase the resistance of the millivoltmeter without increasing in like degree the resistance of the shunt, and hence there is no automatic compensation, as in the case discussed above, where the busbar itself serves as a shunt.

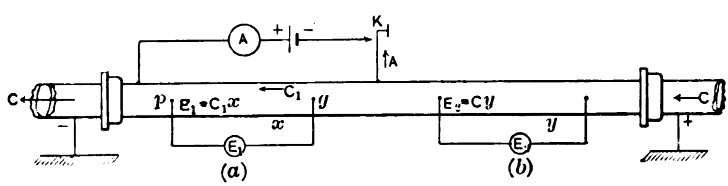


FIG. 5.

To make the millivoltmeter read directly in amperes requires of course, that the constant K, in equation (**8**), be correctly chosen. As we are at liberty to give any value to the resistance, r_{20}, it will always be possible to do this.

Measurement of the Resistance of Underground Mains. An important application of the methods above described for measuring the resistance of a portion of a closed circuit is the determination of the resistance between two selected potential points upon an underground gas or water main. Underground pipes are subject to deterioration from electrolysis, caused by " tramp " currents which get into the pipe line from neighboring electric trolley roads. The electrolysis occurs when current *leaves* the pipes. It becomes important, at times, to be able to quickly and accurately measure the *current* which flows in some selected section of a pipe line. It is evident that this can be easily accomplished by measuring at any time, with a millivoltmeter, the potential drop between the points on a section of pipe, provided the *resistance* between these two points has been previously determined. The method shown in Fig. 5, which is a slight modification of those described above, enables this re-

sistance to be measured with considerable precision while the section of pipe is in place in the pipe line.

The measurement is made with two millivoltmeters and an ammeter. One or two cells of storage battery are also required. The cells of storage battery, a key K (Fig. 5) and the ammeter A are joined in series and connected at two places, as shown in the diagram, to a section of pipe. These connections are best made by drilling ¼-in. (6.3-mm.) holes about half way through the pipe wall, and driving brass plugs into them. Heavy copper wire connections may then be soldered to the brass plugs. The other connections, which serve as potential points, may be made in a similar manner, but smaller holes and plugs will serve. There should be as much separation as possible between a potential point and the place of connection of a current lead, and these should, perferably, be located at the ends of diameters of the pipe which form with each other an angle of 90 deg.

It is well to take one set of readings and calculate the resistance with the polarity of the storage cell in one direction and then take a second set with the polarity of this cell reversed. In the mean of the two resistances, thus obtained, the error, which results from the flow lines of current from the storage cell not being parallel with the section of pipe between the potential points, is largely eliminated. This is specially the case when there is considerable current flowing in the pipe from other sources than the storage cell.

This error will be small, however, in any case, if the distance between a potential point and the point of connection of a current lead is, say, twice the diameter of the pipe and these terminals are located as above suggested. Referring to Fig. 5 for the meaning of the symbols, we have, as in the cases given above:

With the key K open,

$$\frac{x}{y} = \frac{E_1'}{E_2'} = N \tag{1}$$

and with the key K closed,

$$E_1 = C_1 x \tag{2}$$

$$E_2 = Cy \tag{3}$$

and

$$C = C_1 + A, \tag{4}$$

from which we find

$$x = \frac{E_2 N - E_1}{A} \tag{5}$$

Also
$$y = \frac{E_2 - E_1 \dfrac{1}{N}}{A} \tag{6}$$

or
$$y = \frac{x}{N} \tag{7}$$

In applying the method, one is not in the least troubled by the sudden variations of the current in the pipe which constantly occur, because E_1' and E_2' are read *simultaneously* to obtain the ratio N and then, again, E_1, E_2 and A are read simultaneously to obtain the other necessary values. Three observers, reading at the same moment, obtain correct values; for when the current varies, a variation occurs in all three instruments at the same time, the proper *relation* between the readings of the three instuments being always maintained.

This method was carefully tested by the writer upon an actual pipe line with excellent results. The essential features of the

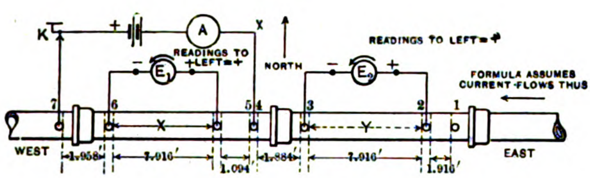


FIG. 6.

test are given to show how the measurement works practically and are recorded below:

The diameter of the pipe was 15 in. (38 cm.). Two pipe lengths were uncovered and the connections to the pipe sections were made at distances and in the manner shown in Fig. 6. The method embodied the use of two cells of storage battery, which would yield on short circuit, when joined in parallel, 125 to 150 amperes, and also one ammeter reading to 200 amperes and two millivoltmeters giving a full scale deflection with 20 millivolts. In circuit with the ammeter and storage cell a single-pole current switch, K was used. The following readings were taken:

E'_1 and E'_2 were read simultaneously. The current in the pipe was sufficient for the purpose. The mean of nine readings of E_1' was 7.511 millivolts and the mean of nine readings of E_2' was 7.122 millivolts. Hence the value of the ratio $\frac{x}{y}$ was

$$N = \frac{7.511}{7.122} = 1.055$$

There were then taken seventeen sets of readings of E_1, E_2 and A with the positive pole of the battery cell joined to No.7 terminal (Fig. 6) and a like number with the negative pole to this terminal.

The following table exhibits a few sample readings.

Current + to No. 7 Terminal				Current – to N. 7 Terminal			
E_1 milli-volts	E_2 milli-volts	A amperes	X = Ohms for 7.916 ft.	E_1 milli-volts	E_2 milli-volts	A amperes	X = Ohms for 7.916 ft.
—6.8	1.6	116	0.0000731	7.60	0.4	—102	0.0000703
—6.2	1.8	110	0.0000736	7.8	0.8	— 98	0.0000709
—8.3	0.9	127	0.0000728	8.2	1.0	—101	0 0000707

The mean value deduced for X with the current from the storage cell positive to terminal No. 7 was 0.00007315 ohm, and, with the current from the storage cell negative to terminal No. 7, it was 0.00007077 ohm. The mean of these two results was 0.00007196 ohm for a length of the pipe of 7.916 ft. There were 40 ft. (12.2 m.) of No. 14 wire used, as potential leads, to each millivoltmeter. Calculation showed that to correct for the resistance of these leads the final value of X should be multiplied by 1.088. Doing this and reducing the resistance to a length of one foot (304.8 mm.) of pipe, the final value found was: 9.91 microhms per foot, at 65 deg. fahr.

The test was defective in that the distances between potential points and points of attachment of current loads were not chosen as great as they should have been and were all made on the top side of the pipe. The " tramp " currents in the pipe were large and very variable at the time of the test. In spite of this the resistance measurement is probably correct within 1.5 or 2 per cent, and should have been better.

It was found in this test that care had to be exercised to give the readings of the three instruments the proper algebraic signs. By making a diagram, like Fig. 6, before beginning the test, errors of this character may be avoided.

George F. Sever: Assuming that this method of Dr. Hering's is correct, which it undoubtedly is, and perfectly available for measuring current in pipes, what are we going to say in court to the jury, or to the judge, when we do find current in the pipe, and it is recognized that current, when leaving a pipe, under most circumstances, causes corrosion? A cooperative test by the parties in interest will undoubtedly show current on the pipe, and if both parties in interest go into court with this statement, it becomes a very difficult matter, at least for the railroad company, to defend the presence of current on these pipes.

If we agree that one ampere on a pipe causes a certain amount of electrolytic effect when leaving it, and then find 100 or 200

or even 500 amperes on a pipe, it becomes a very difficult matter for the railroad company to say that there is no damage. In other words, if there is found any current on the pipe, might it not cause damage at all sorts of places, and can the railroad company, which is alleged to put the current on the pipe, defend its position?

All of these measurements lead up to interesting technical conclusions, but the real common sense question is, how are we going to interpret the results?

Edward B. Rosa: We have been making some study of this subject at the Bureau of Standards. Several years ago we tried the method Dr. Hering has outlined, before we knew that it had been used by him, but we believe that it is not generally necessary to determine the resistance of the pipe. You cannot determine the current, with precision, as has been said, as it is so variable, and, therefore, it is not necessary to determine the resistance with precision. We have found that the resistances of different kinds of pipe are sufficiently near together, so that we believe it is practicable to prepare a table of resistances for different sizes and different kinds of pipe. We have obtained samples of different kinds of pipe used for gas and water, and have measured the resistance, and will shortly have a table prepared, which will be in practical form for the use of engineers, so that they may be required only to measure the drop in potential and take the resistances out of the table. That is not expected to be accurate, as the pipes may have corroded to some extent, but it may be used for approximate purposes, where approximate determinations will be satisfactory, and the table will, undoubtedly, be of very considerable value.

Alexander Maxwell: I do not think that Dr. Hering does entire justice to Haber's earth ammeter, in describing it as merely of academic interest, or in stating that its use involves many assumptions. I have used it extensively, and with very good results.

By means of this instrument, earth currents are intercepted and measured; and while it is true that the soil conditions are somewhat altered, that is of little importance if the path of the current through the soil is of any considerable length, which is nearly always the case. However, it is generally not of the first importance to exactly reproduce the normal conditions quantitatively. It is of much greater importance to determine whether current does flow or not, and to determine its direction and its source. The actual normal value of the current is only a matter of secondary importance, since the total amount of current lost from an entire pipe line may be quite accurately determined by other means, where it is necessary to determine it at all.

In my opinion, too much stress is sometimes laid upon the total amount of current lost from a particular pipe, or from a system of pipes, since this is often a matter of no particular importance. A comparatively small amount of current escaping from a pipe

may produce corrosion over a limited area, and yet the whole pipe will be made useless, just as though it had been corroded over its entire surface.

The earth ammeter is actually a very useful instrument, and when properly used it is capable of indicating conditions which are otherwise obscure. Moreover, when its indications are observed simultaneously with other quantities, such as potential difference, or the main current flowing in the pipe, the source of stray current may be identified by means which involve no questionable assumptions. Thus, as in Fig. 7, where it is suspected that current is escaping from a pipe and flowing to a street railway rail, the earth ammeter may be placed in the earth between the two structures, and by setting it successively in three planes the direction of the stray current may be quite definitely determined. A still better way to do this is to employ three instruments, set as above, and read them simultaneously.

Measurements such as these, taken simultaneously with measurements of potential difference between the two structures, constitute good evidence of the existence of the suspected stray current, and good evidence of its identity. It is even better to

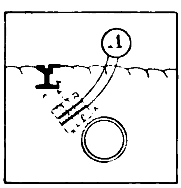


FIG. 7

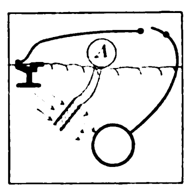


FIG. 8

obtain 24-hr. records of the quantities, by means of recording instruments.

The main object of tests of this character is to prove that stray currents from some suspected source do actually escape from the pipe being tested. The earth ammeter can be used to indicate the escape of currents much smaller than those which could possibly be determined with any accuracy by even the most refined methods for measuring the total current in the pipe. The loss may be even less than 1 per cent of the total current in the pipe, and still produce measurable indications in the earth ammeter. It is well understood that even such small currents may produce serious corrosion, and, in fact, it is the usual condition that stray currents flow on to pipes, and escape from them, in very small amounts, as reckoned for units of pipe surface.

Another useful application of the earth ammeter for the identification of stray currents consists in shunting the conducting path through the soil, by means of a heavy bond connection between the two structures which, with the soil, constitute the circuit for the stray current. This general arrangement is

shown in Fig. 8. In this case, if the earth ammeter shows a certain current flowing between the pipe and the rail with the shunt circuit open, and this earth current is reduced in value when the shunt circuit is closed, excellent evidence is obtained of the actual flow of stray current through the earth.

I am of the opinion that stray earth currents can be detected, measured and identified by means of the earth ammeter, in cases where a survey based merely on measurements of total current in the pipes would not adequately indicate all of the places where current enters or escapes from the undergound structure being investigated.

With regard to the main feature of Dr. Hering's paper, namely, the methods of calibrating the pipe resistances, I have employed the last method described in the paper since 1908, generally utilizing the stray current itself, by means of a temporary bond connection to the street railway rails. I have, however, only found it necessary to calibrate pipes in this manner for very special cases, generally finding the calculated resistance amply accurate, since measurements of such fluctuating quantities as stray railway currents cannot be even observed with great accuracy.

This same consideration of accuracy affects the choice of instruments, and I have found that portable pivoted instruments of relatively high sensibility for their class are decidedly preferable to reflecting instruments as used by Dr. Hering. In short, a large number of significant readings of moderate accuracy provides a better basis for preparing a case than a few observations of wholly unnecessary precision.

Frank Wenner: This method that Dr. Hering has described for measuring currents in pipes seems to be a perfectly obvious method. I personally know of a number of persons who have thought of the method, and I should like to point out that it was used by Professor Adams in Columbus about fifteen years ago, and in that particular case—it was a court case in which the matter of resistance of the pipe was brought into question—he used the method for measuring the resistance as well as measuring the current.

In this particular method, a high degree of accuracy cannot always be obtained, especially in large gas pipes if the current to be measured is comparatively small. The difference in temperature between the two points of the pipe to which the potential connectors are attached may amount to a degree or even to two degrees. Since the thermo-electromotive force amounts to about fifteen microvolts per degree difference in temperature, if the potential connections are copper, serious errors may be introduced where the currents are small and the pipes large and of low resistance. The thermo-electromotive force may cause errors either when the method described by Dr. Hering is used or when the ordinary method, using a sensitive millivoltmeter, is used.

Clayton H. Sharp: In electrolytic surveys and studies all methods are useful, at some times. Conditions are varied, and while in general the method of estimating the resistance of the pipe is sufficient, yet there are times when a method like the one which has been presented to us in this paper is bound to be useful. I think that we are indebted to Dr. Hering for bringing it to our attention, and for smoking out a whole lot of people who have been using it and saying nothing about it.

Carl Hering: Dr. Sharp has already answered one point which came out in the discussion; when members of a profession like ours keep their methods of measurement secret, they are not doing their duty to their colleagues and it is not creditable to them to come out afterwards with claims of priority when someone takes the trouble to publish a description. Moreover I do not admit that the alleged prior methods described in the discussion were really the same; Professor Ganz's certainly was not.

It has been said in the discusson that such precision as is indicated in this paper is not necessary; in most of the ordinary cases it is not, but in a legal case, in a suit in court, it is necessary or else the results will not be sound legal evidence. Furthermore, one of the principal points in this case was to find the current entering or leaving the pipe, and unless the original currents are measured accurately, you cannot depend on their differences. If, for instance, one is 100, and the other 98, an error of only 3 per cent in these measurements may even change the sign of the result.

Professor Ganz upheld the method of *assuming* the resistance and then measuring the current with a millivoltmeter. I do not believe in virtually assuming the thing you are going to measure; it is a very easy way to get results, but I do not approve it. It is moreover dangerous to assume a resistance for a pipe, for the reason that pipes are laid much thicker in the valleys than at the tops of hills, and the gradations are rather small; for that reason alone it is unsafe to assume that any particular length of pipe has any particular thickness, unless you have laid the pipe yourself and know just what the thickness is.

As to the 24-hour measurement that Professor Ganz spoke of, it is hardly necessary, in most cases, to run such identification tests for 24 hours. In fact, a measurement continued over a period of one hour will generally give you two saw-tooth curves that are so nearly alike, that you have enough evidence to show the court that the street railway is the offending party.

I do not wish to say anything against Haber's earth ammeter, as it is very ingenious and undoubtedly very useful for certain purposes, but it will not do for the purpose for which I wanted these measurements.

As to who originated the system, that is of little general interest. I agree with Dr. Sharp that a person who has used some system which is valuable to others and does not make it public

in a paper or some other form of announcement, has no moral right to come out afterwards and claim originality.

Carl Hering (communicated after adjournment): In examining more carefully such broad, vague, general and sweeping claims of priority as those made in this discussion, I have often found, in other cases, that the alleged prior method was not the same one at all, but that it lacked the very elements which characterize the method whose originality is disputed. Several of the speakers evidently overlooked the important statement that this method was devised specifically to determine the current which enters or leaves a pipe, as distinguished from the current flowing in the pipe; for the latter purpose I admit that the very simple method of *assuming* the pipe resistance would be good enough for many purposes, and perhaps even for some legal cases; but I do not believe that any of those speakers will claim that a method based on assumed resistances would be satisfactory or reliable when the result sought is a *difference* between two readings which may at times be nearly equal, and when a lawyer attempts to discredit it to the court.

I grant that Dr. Northrup devised the particular modification described on page 1157 without knowing that I had devised exactly the same one a year or two earlier; I preferred to use the others in most of the tests because the instruments I had to use were not considered to be sufficiently reliable for this method. I cannot grant him, however, that any "precision and generality" was "added" when he devised it independently; as they are identical, one cannot be more precise or more general than the other. Whether my description of it in this paper was "vague," as he claims, I am willing to leave to others to judge.

DISCUSSION ON "ELECTRICAL TRANSMISSION OF ELECTRICAL MEASUREMENTS" (BLISS).
"METERING LARGE DIRECT-CURRENT INSTALLATIONS" (MAGALHAES).
"MEASUREMENT OF ENERGY WITH INSTRUMENT TRANSFORMERS" (MAXWELL).
"WHEATSTONE BRIDGE—ROTATING STANDARD METHOD OF TESTING LARGE CAPACITY WATT-HOUR METERS" (INGALLS AND COWLES), BOSTON, MASS., JUNE 28, 1912. (SEE PROCEEDINGS FOR JUNE, 1912.)

(Subject to final revision for the Transactions.)

William J. Mowbray: It is somewhat presumptuous for me to congratulate Mr. Ingalls on this paper, but I will presume to do so, because I think that I can claim being the originator in the United States of the rotative watt-hour test meter. Some six or seven years ago, I think perhaps it was in 1905, the Chairman of this meeting, Mr. Robinson, presented a paper entitled "The Oscillograph" at a meeting of the Institute held in New York City, and at that same meeting I had the honor of presenting a paper which disclosed for the first time the method of testing watt-hour meters with a rotative watt-hour test meter having several current and potential windings. The paper was entitled "Maintenance of Meters," and brought in the rotative test-meter. At that time this method of testing service meters was not generally used at all having just been started in Brooklyn and New York. Boston was then using a standard resistance voltmeter and stop watch. But I see that Boston has now fallen into line, and is not only using the rotative watt-hour test-meter, but has added to the method of using it a degree of refinement that is characteristic of Boston. I congratulate Mr. Ingalls on this method which seems to be very clever and refined and just the thing for testing these large meters on fluctuating loads.

F. P. Cox: I have been familiar for some little time with the work that Mr. Ingalls has been doing with this method of testing. I do not feel I could pass the paper without saying it is a good and useful method.

Referring to Mr. Magalhaes' paper, and method 3, it seems to me the object of meters is to get a record of the energy used, and if this is the most accurate, as it certainly is, it is worth the money the extra meters cost.

As to getting a totalizing dial, this is quite a problem. I have done a little work on it in the past, by magnetic contact from different meters, to record the sum of the impulses, but the trouble in that case is that sometimes many impulses come in at once, from the different meters and they must all be recorded. To do that, you find it necessary to record on the totaling dial one impulse, and then the others will have to wait and stand there until they get a turn to record; it can be done and has been done, but the device is rather expensive and rather complicated, and if you should add this to the already large expense of the separate meters, I am afraid the man who is paying the

bills would object. But the separate meters and adapting the meter to the circuit, is the right way to do it, and if the job is worth doing at all, it is worth doing right.

In regard to the shunt meter, that has possibilities; it also has its troubles. I do not know how Mr. Magalhaes proposes to connect these things so as to do away with the troubles of the division, because if you are using the shunt meter, as the total carrying meter, you still have the problem of one large meter against several small meters, and you have additional things to look after in regard to contacts. When you are shunting five or ten amperes, you have the larger losses in the higher capacity meters, because you would have the drop which would come from the low capacity. If these temperature effects and loads come in, while you would get a system which would be more flexible, I doubt very much if it would add to the accuracy of the meter. It has not been overlooked or forgotten, but it has troubles. We cannot say they never will be worked out, but I have not yet seen anything that is entirely satisfactory.

J. R. Craighead: First, with reference to "Electrical Transmission of Electrical Measurements." There has been a constantly increasing call for various kinds of measurements which are to be recorded at a considerable distance from the place where the actual measurement is made, and it seems to me this paper shows a method of doing this in a very satisfactory way with a certain class of instruments. However, there is an alternative way of doing the same thing, namely getting the measurement at the point where you want to have it, which consists in designing a special type of current transformer, in which the secondary current shall be reduced, for instance, to 0.5 ampere, instead of 5 amperes. It is perfectly practicable to make a current transformer with 0.5-ampere secondary of practically the same qualities as the 5-ampere secondary.

It is also perfectly practicable to make an instrument employing most of the standard types, of 0.5-ampere capacity, instead of 5 amperes capacity. The load of this instrument on the current transformer is about the same fraction of the capacity of the transformer in one case as in the other. This leaves the same difference, which may be used up in the line drop. If we take an ordinary current transformer, of 5 amperes capacity, we are limited by considerations of load to a small line drop, so that the practicable distance with the usual size of wire is only a few hundred feet if satisfactory accuracy is to be secured. By cutting the secondary down to 0.5 ampere, we multiply the length of the line using the same wire, and consequently the distance to which we can transmit over that wire, by 100, in some cases running to 10, 15, 20, or even 40 miles, the size of wire necessarily increasing with the length of the transmission.

There is one difficulty in connection with this method of building current transformers which ought to be considered, and that is, that the secondary has naturally a very much larger number of turns than the standard current transformers, and

in consequence, if the secondary is accidentally open-circuited, the voltage on the secondary will be ten times larger than on the corresponding 5-ampere secondary. This implies rather special care in insulating the secondary to avoid damage.

As far as the potential transformers are concerned, for ordinary purposes, the line drop may be considered as part of the resistance of the instrument, and the ordinary potential transformer will therefore answer in many cases. For extreme cases, a higher voltage secondary may be used.

In regard to the paper on "Measurement of Energy with Instrument Transformers," I want to say one or two things. One thing, particularly, is in regard to the use of the light-load adjustment for compensation. That has been argued a number of times, and I do not think we can say very much that is new. If we are going to cut down the safety against creeping by calibrating the meter to run fast on low load, we are going to increase the percentage of meters which actually do creep. It does not mean that the meter will necessarily creep because that is done to it, but simply means that out of a large number that are so calibrated, the number of meters that would creep is increased, and the result is that this method should not be used where a large number of meters are to be without examination for long periods. If the meter can be inspected frequently, as is usually the case where high accuracy is desirable, then the method of correction may sometimes be used with good results.

Mr. F. V. Magalhaes: I wish to emphasize the value of the apparatus Mr. Ingalls has developed. It is a combination of instruments and apparatus which are commonly used and owned by most of the large operating companies. He obtains an instrument which will properly check the watt-hour meters on fluctuating service loads. Stating the point in another way he has produced an instrument by using apparatus which is at present developed and in use, and does not involve the design or development of new instruments. It is merely a combination of existing apparatus.

In connection with Mr. Maxwell's paper, the errors in performance of meters used with well designed current transformers are small. It must be borne in mind also in analyzing these errors with a view to reducing them that with the present knowledge of current transformer design and performance any appreciable reduction in these errors is obtained only at a practically prohibitive increase in the physical dimensions of the transformers.

W. H. Pratt: Mr. Magalhaes' paper brings out a point which I wish to emphasize, and that is, in using current transformers for meters, the best current transformers should be selected. Meters ordinarily are expected to work over a very long range, in fact, I think that the meter has to take care of a longer range of observation, you might say, than almost any other piece of apparatus which is used in ordinary work. There is a vast dif-

ference between the good qualities of the current transformers that are available on the market, and by selecting those that have the best characteristics you have almost no trouble. Slight errors in ratio can be taken care of in the calibration of the meter and likewise the phase angle can be taken care of by an adjustment of the lag angle of the meter, if limiting accuracy is required.

In Mr. Craighead's discussion, I think he undoubtedly has in mind current transformers which have also come under my own observation, which depart so far from ideal accuracy that correction would be unsafe.

L. T. Robinson: I may interpolate a comment here that will perhaps straighten out things. The papers of Mr. Maxwell and Mr. Magalhaes and the comments of Mr. Craighead and Mr. Pratt, are largely considerations of special cases that have come up. You must not read into the paper that all these things apply to all the work which we have to do ordinarily. If you give close attention to what the author says all the way through, it has been plainly brought out that for ordinary service and in general the present conditions are fairly satisfactory.

T. W. Varley: Mr. Ingalls pointed out in the sketch the bridge method of keeping track of the variation of temperature in the meter tested. He says that the drop in each zone is practically 400 millivoltmeters. I would like him to explain how he adjusts these loads.

C. H. Ingalls: The resistances may be measured by a bridge, and from the ratio of the two resistances, the ratio of the current with a balance on the voltmeter, can be readily determined. It is preferable, however, to use two ammeters and then, by adjusting the resistances, get the galvanometer to read zero, and then take the ratio of these currents. Repeated tests have shown that the ratio remains very constant. There is another method. If the two shunts are not electrically connected in a very permanent manner, of course the instrument will get out of calibration. In order to get around that feature, if you want to use two ordinary shunts, that are not specially made for the purpose, by using a differential milli-voltmeter you can obtain the zero reading.

T. W. Varley: Would not it be better to use a double bridge?

C. H. Ingalls: A differential voltmeter that is suitable for that purpose is on the market, I believe.

T. W. Varley: Would it not be better to use a Thomson double bridge? That is an easy way of using it.

C. H. Ingalls: Yes, but this method was also devised by Prof. Laws in his laboratory, but never used outside commercially.

Albert Ganz: If you have the two ammeters, why do you need to know the resistances of the shunt?

C. H. Ingalls: You do not, in that case. Three ammeters may be used for measuring resistances, or you can use two ammeters.

Alexander Maxwell: I think that reference to my paper will take care of most of the comments made upon it. It is there stated that for all ordinary cases, commercial transformers are quite satisfactory. Further than this, almost all other cases can be solved by lightly loading the transformers. The difficulties referred to generally occur where extra load is imposed upon the transformers, such as additional indicating meters, or relay coils. The manipulation of the meter light-load adjustment is altogether a last resort, which, I suppose, would only be employed very rarely. For all ordinary cases of reasonable loading commercial transformers are quite satisfactory.

Paul MacGahan: I agree with Mr. Maxwell as to desirability of using separate transformers for relays and for watt-hour meters. There is a strong tendency on the part of some switchboard builders to connect too many devices to the series transformers so as to economize in cost or space. This practice has been very hard to discourage, as the evil effects were not thoroughly understood by operating companies. It has been the invariable practice of one large company building switchboards to insist on separate series transformers for relays and for watt-meters, and nothing else in series with watt-hour meters when intended to be used for accounting purposes.

An ammeter of low internal drop, and possibly a power factor meter may be also connected in if the watt-hour meter is merely used for operating purposes, and may also be used in connection with an indicating watt-meter as the latter does not require the light load accuracy of the watt-hour meter.

Although large enough series transformers might be built to satisfactorily take care of a watt-hour meter and several other instruments, this would be inadvisable, as two separate smaller transformers would be cheaper. Series transformers with two separate secondary coils on separate cores have been used, one secondary operating the relays and the other the watt-hour meters.

A convenient grouping of instruments on two sets of transformers would be as follows:

One set operating relays, ammeters and power factor meters.
One set operating wattmeters.

Elmer L. Kyle: Independent of the fact that shunted type watt-hour meters may be used in future installations of large capacity meters, there are a comparatively large number of the series type still being built and many are in use at the present time. The testing of the present type is rather awkward and in many cases inaccurate, especially in testing those of extremely large capacity. In the later case it is practically impossible to test them except by the use of switchboard instruments.

The method devised by the authors of the paper is fundamentally simple in principle, easily manipulated, and the device is conveniently transported, making it possible more readily and

more frequently to test and maintain the accuracy of the large capacity meters.

The importance of this class of testing may not be fully appreciated but the increasing demands for large loads makes it quite a matter of importance to electric lighting and power companies.

I might also add that although certain types of shunted meters possess the redeeming feature of testing in service with a comparatively low current, the method outlined by Mr. Ingalls and Mr. Cowles is much more desirable since it possesses many of the ideal features in meter testing.

John Gilmartin: It frequently happens that the diversity factor of the natural component parts of an installation is large enough to permit of a much smaller kilowatt capacity of meters to be installed if the total load is metered at one point than if method No. 3 followed.

The light and full load accuracy of registration will be higher on the main meter or meters than on the sum of the individual meters.

For example in an installation large enough to come under the heading of this paper, it is unlikely that janitor work etc. would be performed only on one floor or in one building at the same time.

The usual result would be that instead of the individual meters working at favorable loads, they would each operate at a comparatively small load and it is probable that if main meters had been selected with proper consideration of the diversity factor they would operate at a more favorable point on the accuracy curve than the individual meters.

The same reasoning holds for large installations having a number of motors, the diversity factor of which is frequently large.

Method No. 3 as pointed out in the paper is very well adapted to metering separate converters or, as was shown in a recent case that the writer investigated, to the metering of separate generators in a power station.

It is the usual practise to operate generating units up to at least half-load rating thus giving a very favorable condition for high meter accuracy, while on the other hand, if meters are installed in the station bus they will operate at small loads a considerable part of each twenty-four hours, because the load curve of the meters will follow the station load curve.

Discussion on "Metallic Tungsten and Some of its Applications" (Coolidge), and "The Convection and Conduction of Heat in Gases" (Langmuir), Boston, Mass., June 25, 1912. (See Proceedings for June, 1912.)

(Subject to final revision for the Transactions)

C. M. Green: Dr. Wientraub of the research laboratory at Lynn has suggested a new use of tungsten, that is as a substitute for platinum leading in wire for rectifier tubes. I am thoroughly satisfied from experiments I have made that it will be better than platinum. The specific resistance is about one-half that of platinum, or about 5 to 6 microhms per cu. cm., while the platinum which we use at the present time is about 13 to 14 and the platinum used a few years ago had a specific resistance of 30 to 40 microhms.

A Member: I was very much interested in Mr. Coolidge's paper and I tried in the first instance to see if the tungsten could be plated with copper. I was interested in his statement that it could be wet with copper, and I would like to inquire if he has ever tried to find out whether the metal could be plated with copper, because, if it could, it would be very easy to solder it to other metals.

William J. Hammer: I would like to ask Mr. Coolidge whether he has observed any special changes in the characteristics of tungsten while it is being gradually heated. I recall that in Mr. Edison's very early experiments at Menlo Park, whereas his platinum would only give a light of say from three to four candle power before it melted, by gradually putting little increments of current through the platinum the occluded gases were driven out and the metal was made more dense and became so hard that a sharp file would not mark it, and in this condition the platinum could be brought up to an incandescence of from 30 to 34 candles without melting. Mr. Edison also alloyed the platinum with iridium in many of his lamps.

Carl Hering: I would like to ask Mr. Coolidge how the tungsten acts when used as electrodes, and whether it will stand the oxidizing influence in being used as an anode in the ordinary electric light.

W. D. Coolidge: The question has been raised as to whether tungsten could be plated with copper. That is possible and fairly easy, and it is possible to go ahead as suggested and solder such a copper-plated piece of tungsten. That method we have not found so satisfactory as the method we are now using with molten copper, the adhesion not being anywhere near so firm as we get from the present method. The plating goes best in a copper sulphate solution. Mr. Hammer raised a question about occluded gas. We have done a great deal of work along this line and have found that the greater part of the gas which is in the drawn wire comes off very quickly when the wire is heated in a vacuum. Dr. Hering raises the question of whether tungsten can be used as an anode for electrolysis. As a matter of fact tungsten is oxidized and goes into solution very readily indeed

under such conditions. We had hoped that it could be used in place of platinum.

H. M. Hobart: In the latest edition of the A. I. E. E. Standardization Rules, paragraph 269 relates to the application of temperature corrections to take into account the room temperature on the occasion of tests and to permit of arriving at values corresponding to the reference room temperature of 25 deg. cent. The rule is based on the assumption that the observed temperature rise will be greater the higher the temperature of the surrounding air. My experience does not conform to this rule, but shows rather that the *temperature rise* will generally be *less*, the higher the temperature of the surrounding air. It is very important to engineers that any uncertainty in this matter should be cleared up and I should be pleased if Dr. Langmuir would give us the advantage of his experience and opinions bearing upon this point.

If an electrical machine is to be operated in a place where the surrounding temperature is likely to be high, say 40 deg. cent., then it is very important to be able to know in advance whether a certain machine, tested at, for example, 20 deg. cent., and then sustaining a temperature rise of 40 deg. cent., will, under the conditions of its practical operation in the hot location, have a rise of 44 deg. cent., or only, say, 38 deg. cent. At present the data are very conflicting, and some engineers would be of the opinion that the rise when the surrounding temperature is 40 deg. cent. would amount to 44 deg. cent. thus bringing the temperature of the machine to 84 deg. cent., while the tests to which I allude would indicate that the rise would be somewhere between 36 deg. and 40 deg. cent., say 38 deg. cent., thus making the actual temperature of the machine, when the surrounding atmosphere is 40 deg. cent., only some 78 deg. cent.

Any information which Dr. Langmuir could furnish in this matter would be of much value.

Irving Langmuir: In reply to Mr. Hobart's question, I would like to point out that there are apparently only two factors involved in convection: first, the heat conductivity of the air, and second, the thickness of the film which determines the shape factor. In quiet air this shape factor can be calculated in the cases of wires and plane surfaces. However, in other cases (as where several wires are close together or where we have a confined space, such as might exist in the armature of a dynamo) this shape factor would be difficult to calculate, but in any case it is probably nearly independent of the temperature, and we may say that the heat convection would vary with the temperature practically only because of the temperature coefficient of the heat conductivity of the air itself. Since the latter nearly doubles with the 300 deg. rise in temperature, it is apparent that the convection should increase with increase in temperature of the air in which convection takes place.

DISCUSSION ON "ELECTROLYTIC CORROSION OF IRON BY DIRECT CURRENT IN STREET SOIL" (GANZ), BOSTON, MASS., JUNE 25, 1912. (SEE PROCEEDINGS FOR JUNE, 1912.)

(Subject to final revision for the Transactions.)

Carl Hering: It seems to me that the tests made by Professor Ganz are very valuable, and we are fortunate to have had the benefit of his experience. But I think that to speak of voltage as Professor Ganz does in this paper, is somewhat misleading. The voltage for the electrolytic corrosion of iron is negative. Therefor it should be possible that with no external voltage at all there might be some corrosion. There are always two voltages, one at each electrode, and we generally refer to their sum, as it is difficult to separate them. The result described was perhaps due largely to "over-voltage" at the copper electrode which he used. In my opinion there is also an important mechanical effect in underground electrolysis in the form of the rate of diffusion of the liquid which does the elctrolyzing. If that liquid cannot circulate rapidly there will be much less electrolysis than if it can, and it therefore seems to me that this effect of the circulation of the liquid through the soil is an important factor in determining whether the corrosion will be bad or not; it must also have a very decided effect on the voltage. Professor Ganz says nothing about the inside of the pipe and whether the results there are the same or not.

Edward B. Rosa: Regarding the excessive loss of weight by corrosion, it does not seem to me that it is necessary to assume that it is due to the removal of metal by mechanical means. At the Bureau of Standards we have made some similar experiments, and under some conditions the excess above the calculated value is considerable. It is well known that if iron pipes are embedded in cinders or in certain soils, the corrosion may be very greatly accelerated. I have known of one case where a line was laid through cinders and the pipe was destroyed within a year without the application of any outside current whatever. If the current puts the surface in a different condition from the surface of the pipe exposed as a blank experiment, the local action of self-corrosion may be thereby accelerated. These experiments are of great importance, and I think they emphasize the need of making laboratory experiments under as nearly as possible practical conditions. I believe that in this paper the author should have used the word resistivity instead of resistance to convey his meaning.

Irving Langmuir: The corrosion of the pipe and the consequent loss in weight, in excess of that calculated by Faraday's law, must be due to oxidation. The iron in the ferric condition reacts with the iron itself to produce iron in the ferrous condition, thus causing a greater corrosion of the pipe. Some experiments made at Stevens Institute several years ago threw some light on the pitting. We placed two iron plates in the soil and passed a current between them for several days. At the end of that time we opened the circuit and found that there was a potential difference between the plates, in the same direction as

the original current, thus tending to maintain the current. Therefore, if the current leaves a pipe at one place with a little higher current density than at another, there will be a voltage set up at that place which will make the current concentrate at that point. The explanation of this is difficult to find. There are one or two other cases where a similar phenomenon is noticed. For example, the same effect may be observed with hydrochloric acid alone. If a current of very low density be passed between two platinum electrodes in a dilute solution of hydrochloric acid through which hydrogen is bubbling, it is found, upon opening the circuit, that there is a difference of potential between the electrodes in the same direction as that which originally produced the current. This effect, however, persists only a short time.

C. H. Sharp: The idea that I desire to express about the excess of corrosion over and above the theoretical amount, is that the action of the current accelerates the normal or so-called "chemical" oxidation of the iron. Consequently the ordinary oxidation goes on more rapidly when the current is flowing than when it is not. One interesting thing is Professor Ganz's suggestion as to the reason for the greater durability of cast iron pipes than wrought iron and steel pipes, explaining the fact on a rational basis. He did not say anything about scale or about surface conditions or anything like that, but he showed that the higher resistivity of cast iron alone would result in greater durability.

A. F. Ganz: Dr. Franklin's suggestion of using quicklime or caustic soda has been tried. Dr. Hering spoke of the voltage I have measured as being insufficient. These are practical tests and I was measuring the voltage of the pipe being corroded. The inside of the pipe of course is not exposed to the soil and therefore was not being corroded under the conditions of the test. Dr. Rosa speaks of the excess of the corrosion over Faraday's law as being due to natural corrosion. I do not believe so, because in every case duplicate tests were made. Two wrought iron pipes were taken and placed in clay and loam soil and one subjected to electric currents and one not subjected to electric currents; and the loss and weight in each pipe was noted and the difference in those losses is what I have noted as due to electrolysis. Therefore I have eliminated that natural corrosion of which he speaks. The case is one of electrolytic action as Dr. Langmuir and Dr. Sharp have suggested. I am glad to have had your suggestions because I want to continue these experiments and shall avail myself of them. In order to test out that point regarding oxidation after electrolysis has commenced, I should think if two experiments are started at the same time, and certain currents allowed for a week or two, and then test one immediately and find the loss, and allow the other experiment to continue for a month without any current, you could then see whether during that month there is a greatly increased loss.

DISCUSSION ON "PRINCIPLES TO BE CONSIDERED IN SELECTING A WATERWHEEL UNIT" (COLDWELL), PORTLAND, ORE., APRIL 18, 1912. (SEE PROCEEDINGS FOR APRIL, 1912.)

(Subject to final revision for the Transactions.)

L. F. Harza: The author has opened up for discussion one of the most important and by no means the most simple problem of hydraulic engineering with which the modern electrical engineer is compelled to deal if he is engaged in hydroelectric work.

It has been my good fortune to have been associated with Mr. Daniel W. Mead, during the time that he was preparing material for his book upon "Water Power Engineering," published in 1908, in which some new material upon the subject of turbine hydraulics and turbine selection was presented, and also to have had the opportunity since that time of frequently applying the methods there outlined. The application of these methods since that time has served but to emphasize their usefulness, although to simplify and to modify them in some minor respects.

In discussing this paper it is my purpose to briefly outline these methods in the hope that they will prove of interest to this Society as also to substantiate some conclusions at variance with the author.

The author's statement that "in many instances very little engineering is being used in the selection of waterwheels" is very true. The speaker has been told by the chief engineer of a leading waterwheel firm that, judging from his contact with the purchasing public, the total number of engineers in the United States, outside of the turbine manufacturers, who could analyze in detail the test of a hydraulic turbine and draw conclusions therefrom as to its operation characteristics and suitability for use under other heads, speeds, etc. than those of the test, is very small.

Whether this is true or not, it is certain that most purchasers look principally toward the mechanical features and the manufacturers' guarantees in the selection of their turbine equipment, these guarantees often applying to only one or perhaps two points in the efficiency curve, leaving other features entirely to the manufacturers.

Although the speaker does not wish to depreciate the importance to the investing public of rigid performance guarantees, or to intimate that the manufacturers do not know far more about turbines than a consulting engineer, yet there are certain facts and conditions, both engineering and commercial, in the waterwheel business which emphasize the importance of a deeper study of the hydraulic features of a waterwheel proposal than it commonly receives. An understanding and appreciation of these conditions can only be gained by a detailed study of the hydraulic features of type representatives of the wheels of each of the manufacturers. The writer has had occasion to make such studies during the past few years and they have brought

out some facts, which will be enumerated and discussed later on, most of which apply particularly to the " high speed " or " American type " or sometimes called " mixed flow " runners.

The first American runners were built by so-called " cut and try " methods. Some very good runners were developed in this way which are still on the market and the equal of some of the best scientifically designed runners of more recent design.

The design of the American type runner is a very intricate problem, much more so than the design of the high head wheels built as nearly pure inward flow Francis types. That the rational mathematical design, however, of good American type runners, based of course also upon general experimental data is practicable within reasonable limits has been shown in recent years in a number of instances where remarkably good results, as regards efficiency, have been obtained without the building of more than one runner to obtain the desired results even though of a type differing from any previously built by the designer.

The complexity and uncertainties, however, of a rational analytical design have led to a system of standard designs all dimensions of which are increased or decreased in the same proportion, as nearly as may be practicable, when a new size of runner is to be designed. This results in the so-called " hand-me-down " runner so common in America and which has been so often assailed by the European builders as well as by some American builders. Nevertheless, some of the best American designers, although fully competent to make a rational design, agree that a homologous change in size of a runner already built and tested can be done with much less uncertainty than a change of type, and after having designed one runner of a type by rational methods runners of other sizes are obtained by homologous proportion.

With developed and tested runners of several types and specific speeds from which to choose, even though not of the size required for a given installation, it is nearly always possible to select a suitable type-representative of some manufacturer which by a change of size, only, can be made to fit a given set of conditions to the best advantage.

To judge of the characteristics of a runner from the test, it is necessary to put the test in graphical form. The Holyoke test is an unintelligible mass of figures until platted graphically. About the only comparison which can be drawn between two tests until platted is as to their relative maximum efficiencies and specific speeds at those efficiencies. It is quite possible that the runner appearing the best as judged from these two characteristics would be found to be undesirable when analyzed graphically.

The important elements in a runner test are: power, speed, efficiency, discharge and gate opening. Several methods are available for representing the relations of these variables graphically.

The representation of three variables really constitutes a complete diagram although several diagrams may be superimposed if their abscissas and ordinates agree. To graphically represent the relations of three variables requires the use of several curves. Either two of the variables can be platted as abscissas and ordinates, the corresponding value of the third variable being written beside each platted point. Lines of equal value of the third variable can then be drawn through these platted points.

Two methods of platting turbine tests are described by Mr. Mead in " Water Power Engineering " as shown by Figs. 1 and 2. and the writer has modified Fig. 2 as shown in Fig. 3, *i.e.*, by substituting power for speed in the horizontal scale and drawing lines of equal efficiency and of equal specific speed.

Fig. 4 is the published Holyoke test of an unusually high speed runner platted as shown in Fig. 1. Fig. 5 is the test of the same runner platted as in Fig. 3.

Each of the two types of diagrams has its advantages. No. 1 is more quickly and more accurately platted than No. 2 or No. 3 and should be used for the acceptance tests on the actual runner purchased. It consists, really, of two entirely distinct diagrams with the speed scales, which are platted horizontally, common to both. The accuracy with which it can be platted is due to the fact that the points in the test are determined by blocking the gate in a fixed position while tests are made at numerous speeds. Lines of equal gate opening therefore pass exactly through these points.

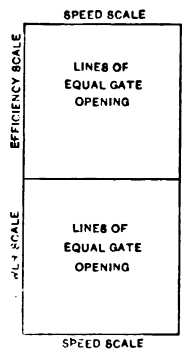
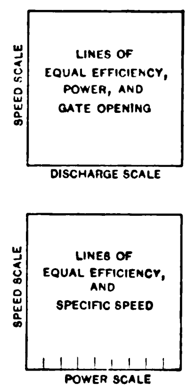


FIG 1.



FIGS. 2 AND 3

In either Fig. 2 or 3 the lines of equal efficiency or equal power must be interpolated between the scattered points, none of the lines perhaps passing exactly through any of these points. The location of these lines may be only approximate, especially toward the edges of the diagram.

The lines of equal specific speed in Fig. 3 are platted exactly, as specific speed is related mathematically to speed and power, as shown by the equation:

$$K = \frac{N\sqrt{P}}{h^{\frac{5}{4}}} = \frac{N\sqrt{P}}{\text{constant}} \qquad (1)$$

These lines have an important use, as will be seen later,

although they are not at all experimental nor any part of the test itself.

Although Fig. 3 is not quite so quickly platted as Fig. 1 nor so accurate to use it nevertheless presents a perfect picture of the operating characteristics of the runner where every feature stands out unconcealed to one accustomed to the interpretation of the diagram. It is highly desirable that a diagram of this kind be made of at least one representative runner of each distinctive type made by a manufacturer.

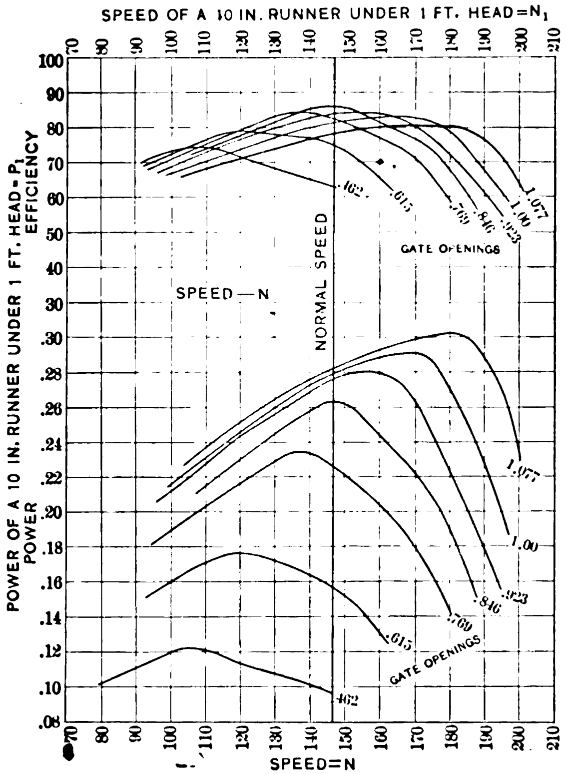


FIG. 4

In a test at Holyoke or in place the head fluctuates for different observations and in all diagrams where speed, power, and discharge are to be platted all observations must necessarily first be reduced to equivalent values of these variables at some assumed uniform head by the following equations (2), (3) and (4).

$$\frac{N_1}{N} = \frac{\sqrt{h_1}}{\sqrt{h}} \qquad (2)$$

$$\frac{Q_1}{Q} = \frac{\sqrt{h_1}}{\sqrt{h}} \tag{3}$$

$$\frac{P_1}{P} = \frac{h_1^{\frac{3}{2}}}{h^{\frac{3}{2}}} \tag{4}$$

$$\frac{P_1}{P} = \frac{D_1^2}{D^2} \tag{5}$$

It is also highly desirable for comparative purposes, although not essential, that all of the runner tests in a given office be

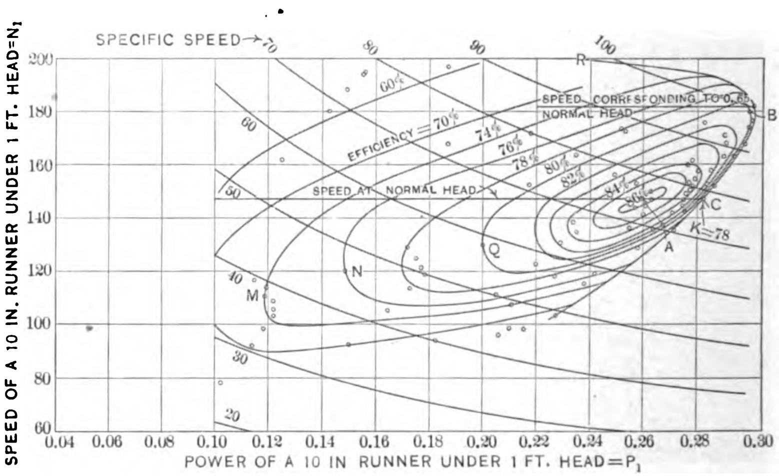


FIG. 5

reduced to equivalent values for a uniform size of runner by equation (**5**). The most convenient head is one foot and the writer has adopted a 10-inch runner as a convenient size to which to reduce all tests.

By adopting these unit values and by preference for Fig. 3 instead of Fig. 2 equations (**2**) and (**4**) combined with equation (**5**) then become:

$$N_1 = \frac{D\,N}{10\sqrt{h}} \tag{6}$$

$$P_1 = \frac{100\,P}{D^2\,h^{\frac{3}{2}}} \tag{7}$$

where N_1 and P_1 are the equivalent values of speed and power reduced to 10-inch size and one foot head.

The computations necessary for platting the Holyoke test shown in Figs. 4 and 5 required the application of equations (**6**) and (**7**), each 95 times, or as many times as there were experiments in the test.

The large amount of calculation required to platt a turbine test is one of the important contributing causes, I believe, of the general neglect of scientific turbine selection. Acting upon this belief the writer has constructed in somewhat crude form for his own use a slide rule for computing equations (**6**) and (**7**) as well as the following equation:

$$K = \frac{N \sqrt{P}}{h^{\frac{5}{4}}} \tag{8}$$

for specific speed. It very greatly shortens the time of the draftsman in making these computations and is so constructed that the reduction of all data to a 10-in. wheel involves no additional work, it being necessary to set the size of runner on the rule only once for the entire 95 computations.

The computations for platting Figs. 1 and 3 are identical so that both may be platted with little additional work.

I will first explain the interpretation of the type of diagram shown in Fig. 3 as exemplified by Fig. 5. The diagram is here platted for a 10-inch wheel under one-foot head, although the actual size and head to be used could be platted if known. Speeds are platted vertically and since the conditions of hydro-electric service require constant speed under all loads, then a horizontal line through the diagram represents the operation of a hydroelectric unit under variable load and constant head.

If the runner is to operate at a fixed load and speed without governing as in some stations then it is evident that its load should be 0.26 h.p. and its speed 147 rev. per min. in order to result in the highest efficiency. This is because the point A thus located is on the crest of the hill if you think of the efficiency lines as comparable with contours.

If water is of little value, as for example where the stream will not be fully developed for many years if ever, then first cost of machinery governs and the runner could be operated at a speed even as high as 180 rev. per min. to develop 0.30 h.p., as shown at point B, thus cheapening the generators and allowing the number of runners required to be decreased in the ratio of 26 to 30, or allowing smaller runners to be used and the speed to be still more increased. If this type of runner were to be used, the economical size and speed of units would need to be determined for each case individually on its merits.

If the runner is to operate with a variable load, then instead of considering a point on the diagram one must consider a

horizontal line. A horizontal line through *B* (180 rev. per min.) would show a very rapid drop in efficiency at part gate with the maximum at full gate. A governing unit must always be operated at something less than full gate to allow for upward load fluctuations. If operated at 180 rev. per min., this runner could then never operate at best efficiency attainable at that speed unless momentarily and would at all times be low in efficiency. It is doubtful if water would ever be so valueless as to warrant operation at this speed under fluctuating load.

It will be noted that the maximum efficiency, Fig. 5, at:

0.12	h.p.	occurs	approximately	at	110	rev. per	min.
0.15	"	"	"	"	120	" "	"
0.20	"	"	"	"	130	" "	"
0.26	"	"	"	"	147	" "	"
0.30	"	"	"	"	180	" "	"

as shown by the points *M*, *N*, *Q*, *A* and *B* respectively, Fig. 5.

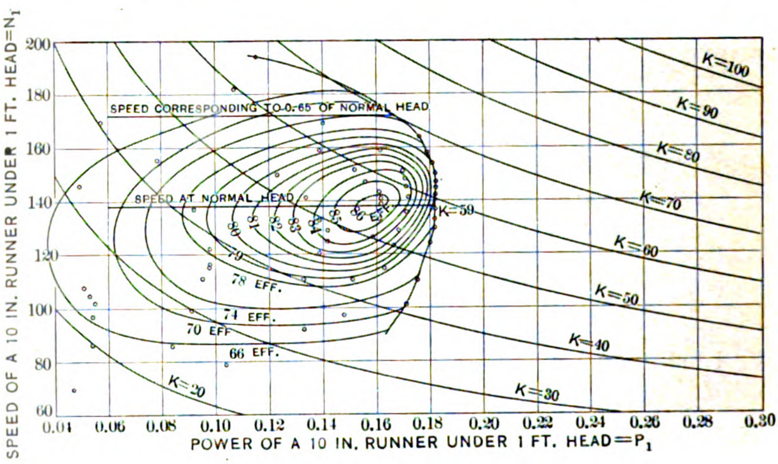


FIG. 6

A lower speed type of runner or lower value of *K* (assumed 78 for this runner) will usually show less variation in the above best speeds at varying loads, although this feature is partly an individual characteristic. This is one of the most significant differences in high and low speed runners. Fig. 6, which shows a test of a somewhat lower speed wheel ($K = 59$ assumed) illustrates this at a glance. The variation in best speed is here only about 18 per cent instead of 39 per cent for the same proportional variation in load.

Fig. 7 shows another high speed runner ($K = 70$ assumed) where the same sloping position of the efficiency curves will be noted as in Fig. 5. In this runner, Fig. 7, a great choice of operating curves can be obtained by selecting different speeds.

For example, if a manufacturer were asked to quote on a wheel having a specific speed of 64 he would be justified in quoting upon this design if the unit is to operate a large part of the time at part gate as is often the case and if the efficiency gained warrants the increased cost of generator. On the other hand, this same type of runner might be proposed for operation as a type $K = 78$ runner if first cost governs and especially if the unit will be operated non-governing. Horizontal operating lines are shown on the diagram for $K = 64, 69, 74$ and 78 and in Fig. 9 the corresponding efficiency curves are shown. Each of these curves is better suited than any of the others for some possible conditions of operation. They all have their proper place. What then is the specific speed of this runner?

After discussing these features it is evident that if one were asked to determine the specific speed of the runner in Fig. 5,

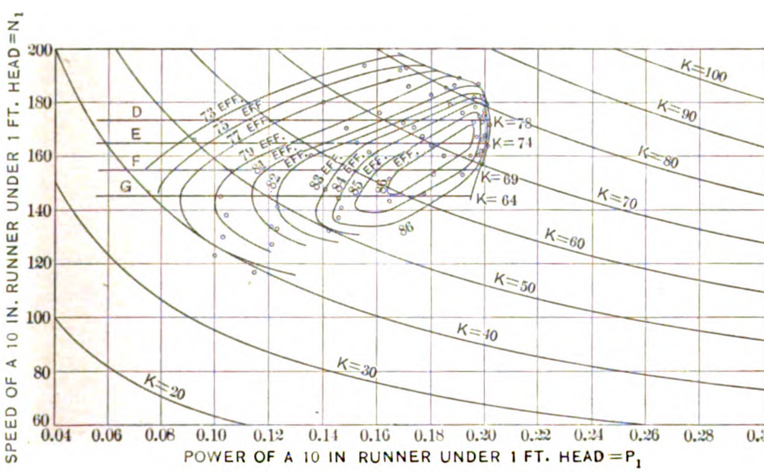


FIG. 7

for example, it would be impossible to do so without an arbitrary rule. This rule usually is to determine the specific speed from the full gate power at the same speed which gives maximum efficiency, or, in other words, where the horizontal line through A intersects the full gate line, or at C.

The lines sloping on a curve from the upper left toward the right and downward are lines of equal specific speed and between them the value of K for any selected point on the diagram can be interpolated as, for example:

At point A, $K = 75$
" " C, $K = 78$
" " B, $K = 99$

I think it will now be evident that to make an intelligent selection of runners more is needed than the value of K at

point C, or than an efficiency curve showing efficiencies only along the one speed drawn horizontally through A and C, especially when it is remembered that two runner-types may exhibit radically different curves when platted in this way, even though the above constants may be alike and even though their efficiency curves platted through the speed of best efficiency be alike.

Figs. 5, 6 and 7 are all platted for 10-in. wheels under one ft. head and for the same range of vertical and horizontal scales. This should always be done, as the several diagrams are then more easily compared by eye and the differences in characteristics stand out more distinctly. In this case the three diagrams have also been changed so that the maximum efficiencies are the same for each.

The adaptation of these curves to a definite size of wheel at any required head and speed is readily made from these curves by means of a change of scale for abscissas and ordinates, or by means of equations (**6**), (**7**) and (**8**).

The ordinary curve between power and efficiency, with which all are familiar, can be platted very readily from either type of diagram, 1 or 3, as exemplified in Figs. 4 and 5 respectively, both of the same turbine.

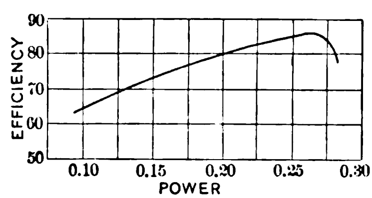


FIG. 8

Suppose it is required to platt this curve from Fig. 4 for a speed of 147 rev. per min., which corresponds to best efficiency. Draw a vertical line through the diagram at this speed and then at the intersection of this line with the power curves in the lower part of the diagram and efficiency curves in the upper part, for the same gate openings, pick off the two corresponding values of power and efficiency and platt as in Fig. 8.

The same curve can be platted from Fig. 5 by drawing the horizontal line through 147 rev. per min. and at its intersection with each of the lines of equal efficiency read the corresponding power along the lower scale and platt.

In Fig. 9 I have platted efficiency curves in this manner for Fig. 7 and at four speeds, marked D, E, F and G on both Figs. 7 and 9. Fig. 9 now furnishes a most excellent example of the value of analysis in selecting a unit. If water is plentiful and load constant the high speed and hence cheap machinery cost corresponding to line D might be selected.

If water is valuable and the load fluctuation is so great that the unit must operate normally at a low gate opening or power in order to have reserve capacity for momentary peaks, then the speed represented by curve G might be selected, or some intermediate speed, depending upon attendant conditions.

The most evident conclusions from the several curves of

Fig. 9 are that higher speed means lower part gate efficiencies and the shifting of best efficiency toward full load.

There is a very natural tendency of a manufacturer, in presenting a runner such as shown in Fig. 7, to recommend it for operation at a higher speed than economical, because of the cheaper generator, especially if he is called upon to guarantee only maximum efficiency and maximum capacity. This gives him a great advantage in competition and catalogue speeds of stock wheels are nearly always higher than advisable for economy except under special conditions. It is the business of the consulting engineer to judge of the soundness of the manufacturer's advice as to speed, etc., and as to whether or not the proposition could have been made more satisfactory by a different speed or type, although perhaps at greater expense, and whether such additional expense is warranted by the results even though costing more than some other proposition submitted. The writer is acquainted with one proposition where 1 per cent in efficiency is worth $20,000 to the purchaser on a total contract price of only about $90,000.

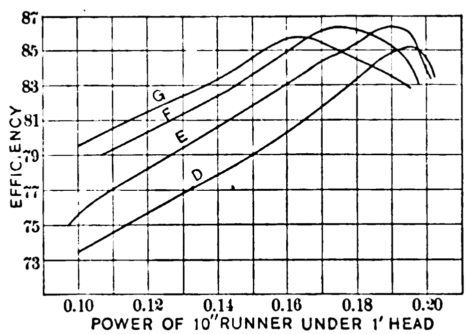


Fig. 9

With the knowledge on the part of the manufacturer that the consulting engineer who will make the selection is competent to, and will make a study of the proposals beyond the scope of the guarantees and mechanical features, the proposals become much more thoroughly worked up and reliable.

It is gratifying to note that in the recent specifications of the Isthmian Canal Commission for turbine equipment for the Gatun station it was specified that a diagram on the principle of Fig. 2 be submitted with the proposal showing the characteristics of the runner to be furnished or of one of homologous design.

Experience in the analysis of turbine propositions has brought out the following points, some of them shown by previous discussion:

1. Manufacturers allow a considerable margin in their guarantees below what they have heretofore been able to accomplish and not all the same margin.

Asked why he did not make higher guarantees in a certain instance a manufacturer said because no one else did, and it was not necessary in order to compete.

Suppose now that one manufacturer, A, guarantees one per cent below B and yet the test of a homologous runner which A submits with his proposal shows that he could probably be expected to furnish a runner some 3 per cent better than B's. If now A will not raise his guarantee, thinking that it is already high enough to win, what relative weight should be given to *guaranteed results* and *probable results?* This is a question which would depend upon how uniformly A's results had exceeded B's.

2. Some manufacturers have not been as successful as others in the development of a given type of runner, and even though equally successful in a general way yet individual characteristics shown by the curves may better fit one maker's equipment for one class of service and the other's for still a different purpose.

For example, one manufacturer's efficiency curves almost invariably peak at almost full gate such as *D*, Fig. 9, and slower speed will not much change this feature as it did in Fig. 9. The equipment is suited, however, for certain operating conditions. Runners also with almost the same curve drawn through the speed of maximum efficiency will often show radically different characteristics for fluctuating heads.

The author of the paper, in discussing turbine characteristics, has assumed " best speed " to be that speed which results in maximum power. In the case of the turbine shown in Figs. 4 and 5 this would cause the turbine to operate at point *B*, very rarely advisable, as previously discussed. If operated at this speed, 182 rev. per min., however, his criticism of high-speed runners to the effect that a drop in head under the conditions of service, which is equivalent to an increase in speed, causes a very rapid drop in power is warranted as shown by the rapid recession of the curved line *B R* which represents the line of full gate power at varying speed.

If, however, this runner is operated normally through *A* and *C* it is still a higher speed runner ($K = 78$) than discussed by the author and yet a dropping head will cause the power to drop at an even slower rate than the three halves power of the head until the head equivalent of 182 rev. per min. is reached. This would allow the head to fall to 0.65 of normal, equivalent to an increase of speed of 24 per cent, with actual ***improvement*** in power above the theoretical.

If operated through *A* and *C* at normal head the full gate power is 0.283 h.p. and through *B* is 0.302. At 0.65 head the power would normally drop to $0.65^{\frac{3}{2}} = 0.524$ of 0.283 h.p. = 0.148 h.p., showing a loss of 47.6 per cent. The individual characteristic of this runner would increase this, however, in the

ratio of $\frac{0.302}{0.283} = 1.067 = 6.7$ per cent instead of decreasing it 28 per cent as the author's runner would do for the same increase in speed, *i.e.*, 24 per cent, as shown by the author's Fig. 9.

On the other hand, the runner illustrated by Fig. 6, although of smaller specific speed, shows a similar *drop* in power of 8.2 per cent for reduction to 0.65 normal head. The gross advantage of the higher speed runner at 0.65 normal head is in this case $6.7 + 8.2 = 14.9$ per cent of the reduced power, or $0.149 \times 0.524 \times 1000 = 78$ h.p. on a 1000 h.p. installation, instead of a disadvantage of 117 h.p. for the two runners considered by the author under 29 per cent increased speed (0.6 normal head) or 57.5 h.p. under 20 per cent increased speed which corresponds to 0.7 normal head.

The conflict between this conclusion and the author's is due to basing it upon another pair of runners. It merely serves to illustrate the fact that:

3. Turbines have individual characteristics which specific speed does not reveal, and general conclusions drawn from individual cases are dangerous.

4. A manufacturer commonly quotes, if possible, upon a wheel which he has already built, the quotation usually being upon a wheel larger in size (if different at all) than necessary, but the nearest to the requirements of any wheel for which he has patterns and dies.

Misfits due to this condition are very numerous and engineers are largely responsible by specifying that a unit must be capable of developing not less than a certain h.p. and must have a certain efficiency at, say, $\frac{3}{4}$ gate, or even at a definite h.p. Two prominent turbine manufacturers in a certain instance named the figure 8 per cent as the margin necessary in design to be safe in developing the guaranteed maximum.

In Fig. 10, I have copied curve *F*, Fig. 9, as being an average operating curve and the form of curve desired for a certain installation. Suppose now that an unusually rigid guarantee was required of the manufacturers, namely, that their results should not fall more than 2 per cent below the desired curve, *F*, at any point, as shown by curve *K*. Now suppose that the runner when built and tested was found to have exactly the "desired" efficiencies at $\frac{1}{2}$ load, $\frac{3}{4}$ load and all other loads but was found to be 8 per cent greater in power than specified. Its efficiency curve was then as shown in curve *J*. This curve falls everywhere above the guarantee and the runner could not therefore be rejected. Nevertheless, it is everywhere from 1 to $1\frac{1}{2}$ per cent below the desired curve due only to excessive size and not to an inferior runner. Yet the manufacturer must design for a power greater than specified in order to *guarantee* that specified.

In the case previously mentioned this fault would have been equivalent to a loss to the purchaser of about $25,000 in value of the equipment.

Power is now generally sold on a kilowatt-hour basis and efficiency means income. Capacity does not produce income except that it allows of carrying the peak load. Additional capacity can always be obtained by means of more units, but inefficiency can not be remedied except to tear out and replace what is already installed. In the case above mentioned the **$25,000** would have more than paid for another unit which would have more than made up the deficiency in power had the units been 8 per cent below specifications instead of above. The remedy in this case was to allow the manufacturer a 4 per cent margin on either side of the desired maximum power.

In one installation with which the writer is familiar and one engineered by a very large engineering company, the hydraulic units actually installed so far exceeded the generators in capacity that the normal generator load if platted on the turbine curve would be in about the relative position of point *H* on curve *F*, Figure 10. Probably the study given to the problem of accepting the units consisted of looking over the Holyoke test to see that at least the required power could be developed

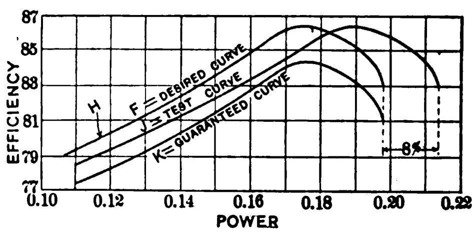


FIG. 10

and that the highest efficiency there shown equaled the guarantee, no attention being paid to whether this efficiency could ever be realized or not without burning up the generator.

Tests of high-head runners are nearly always made after installation and at only one speed so that information as to their operation under variable head and as to their other characteristics is rare. The total amount of data usually consists of one curve such as Fig. 8. The same is true of low head runners tested in place, using the generator as a brake.

It is greatly desirable for the interest of all concerned that tests in place be made at several speeds as is done at Holyoke. It should be possible from the shop test of the generator at one speed to compute its efficiency at another speed with sufficient accuracy for this purpose. If not, it would pay to test it at several speeds in the shop.

In regard to speed regulation the author seems to convey the idea that the slower speed generator has greater flywheel effect in proportion to its greater weight and greater diameter of rotor (*i.e.*, its moment of inertia, $w r^2$).

The approximate formula for speed variation in per cent for open flumes is:

$$\Delta n = \frac{50 \, \Delta E}{0.00017 \, wr^2 \, n^2} \tag{7}$$

Δn = per cent fluctuation of speed.
ΔE = energy required to be absorbed or given out by the rotor.
wr^2 = moment of inertia of the rotor.
n = rev. per min.

From this it will be seen that the variation in speed for the same flywheel is inversely as the square of the speed. A unit with twice the speed of another would need to have a wr^2 only $\frac{1}{4}$ as great, *i.e.*, $\frac{1}{4}$ of the weight of metal at the same distance from the axis or the same weight of metal at $\frac{1}{2}$ the radius, or any equivalent combination.

What is lost in higher speed by a smaller wr^2 is thus at least partially overcome by the greater speed—just what proportion in ordinary commercial designs of generators I am unable to say. I would like to hear from some representative of the electrical companies as to whether he has data to show which is the greater influence. It is usually our policy to determine the wr^2 which will give satisfactory regulation and then specify this value or an equivalent flywheel in asking for generator figures.

The writer has confined his efforts in discussion almost entirely to hydraulic features as I believe they are more neglected in practise and far less perfectly understood by the average hydroelectric engineer than the mechanical features.

E. R. Shepard: The 23d question in Mr. Coldwell's paper which refers to the nature of the water (whether silty or clear) should be one of considerable importance to the manufacturer. I have had some experience with waterwheels in the muddy rivers of the southern states. I have in mind a plant where the wheels, operating under a forty-foot head, lasted three or four and not over five years. The operation of a waterwheel is very sensitive to the angles referred to in the paper and especially to the angle α. That angle is restricted to such narrow limits that it may actually be affected by the thickness of the metal in the blades. If extra thickness be added to the blades to allow for the abrasion of the silt and sand then it is quite possible for the nature of the water to affect the selection of these angles. I should like to ask Mr. Coldwell what effect the clear water of the mountain streams has upon the life of the wheels, and if the manufacturers make any difference in the thickness of the metal for clear water and muddy or silty water.

J. D. Ross: In our turbines with a 600-ft. head we have absolutely clear water, perfectly clear for almost the whole year, and an analysis of it shows only the very faintest trace of any organic matter, no silt. We have pitting on our runners, so that they last but a few months. The pitting is very severe. On light loads there is an action on the wheel that is doing this

work, that looks like electrolysis. At first we supposed it was the poor quality of the steel and we made a bronze runner, and found the pitting occurred in the same manner and in the same places. The bronze was the best hard bronze. The machines were tested for stray electric currents but none was found. These holes sometimes go the depth of an inch, while they are not an inch across. We have tried this action on a nozzle, putting a bolt through one side of the nozzle and turning a high head stream into it, and the parts shaded or protected by the bolt have the paint removed rather than the portions where friction is greatest. In the Pelton wheel we find the paint stays on the face of the bucket where it gets hard hit, quite often. We look for another source for the pitting. We have put on a coating of enamel, in the hope that the action would cease, and we also are plating a couple of square inches with platinum to see if there is anything electrolytic as we believe the action to be chemical and it looks to us as if there is a breaking up either of the water or the air in the water, and the action is like an electrolytic action. In either case atomic oxygen might be liberated as in electrolysis. If there are others working along that line, we would like to cooperate with them.

A. H. Babcock: I think that is the case in a majority of the power houses. I shall describe that. We have some high speed turbines and centrifugal pumps; there are three such pumps run at high speed. On some parts of the runners there is a corrosive action that gives me the impression that the metal was not wholly mixed and that there was a selective dissolving of one element of the mixture, leaving a honeycombed mass of runner. In other parts of the wheels, particularly on sharp edges of the diffusion vanes and the runners, themselves, there will be groovings the same as faults; I have seen that on the buckets and not reached under a high head. The groovings having the appearance of being eaten out by needles. I mean to use that merely as a simile. These difficulties with the waterwheels at Seattle, therefore, seem to be closely parallel with our difficulties in silt water with some sewage, not driven at a high velocity. I should like to cooperate with Seattle to get rid of the difficulty.

W. H. Allen: I wish to cite an instance of two wheels of practically identical design, made by the same manufacturers, one of which operates under a head of about 260 ft. with clear water. It has been operating, I think, over six years with satisfaction. The other operated under a head of about 160 ft. with dirty water. It was completely worn out within about four years and had to be replaced. It was replaced with an impulse type wheel, showing that the character of the water affected not only the design of the wheel, but also the type of the wheel.

Clinton B. Smith: The corrosion of waterwheels seems to be very common. There is an instance in Montana on the Missouri River where in a period of about four months abso-

lutely new runners went down due to this honey-combing on the side of the bucket of the runner. At that time, we had much discussion as to the exact cause of this action, and the manufacturers gave as their opinion that the bucket was probably faulty in outline, causing a bubble to be carried around on the non-pressure side of the bucket and that this bubble of air and gas caused the honeycombing by chemical action. The matter was finally solved by putting in bronze runners which stood up very well, although even these showed a slight sign of action at the same place after a few months of service.

Mr. Coldwell: I was very much interested in the discussion of Mr. Harza. I find that one who is connected with an operating system has but little time to study into the intricacies of waterwheel designs, and I do not wish it to be understood that I am taking the position of being an expert on this subject, for I am not. My function has had to do with the purchase and operating of the wheels rather than design. Mr. Harza's discussion brings out some very interesting things, especially his curves and the discussion of the same.

Mr. Shepard made some timely remarks on the kind of water being supplied to a wheel. In our Cazadero plant we ran for eighteen months—the water is very clear—and at the end of that time even the paint marks were still on the bucket. In fact, the actual numbers placed on them were still discernable. As to the thickness of the runner bucket, I am not sure but that the designers have taken into account this matter of dirty water in their design. The angle α, as Mr. Shepard states, is rather a sharp one, and has pretty close limits, but I don't believe that the designers have found it necessary to go to the extent which Mr. Shepard feels that possibly might have been necessary. Mr. Ross in his plant is a pioneer in the matter of extreme high heads. There are very few plants in existence in the world running at higher heads than in the Seattle plant, and his remarks about the fitting of these runners are certainly very interesting. I am absolutely without experience in those high heads, and cannot offer suggestions. These pumps were used in connection with salt water. I thought perhaps you had in mind the feed water, and we are all more or less familiar with the electrolytic action that takes place there.

Discussion on "Electrical Control of a Large Mine Hoist" (Cheney), Pittsburgh, Pa., April 27, 1912. (See Proceedings for March, 1912. (Continued from November, 1912, Proceedings, page 2060.)

(Subject to final revision for the Transactions.)

M. A. Whiting (communicated after adjournment): In answering the criticism of the high slip (and consequent low efficiency) at full speed, Mr. Cheney stated that where the period of full speed running is long it will be advantageous to short-circuit the motor secondary at the brushes by means of switches. It is extremely doubtful whether any simple and wholly reliable method can be obtained whereby contactors (or other forms of switches) can be used to short-circuit the rheostat automatically when the liquid rises to its maximum level.

Provided that some means can be found for accomplishing this, there still remains another point to consider, viz: the fluctuation of load when the rheostat is short-circuited. In the installation under discussion (see Fig. 13 in the paper), the maximum hoisting speed is 335 rev. per min., representing 10 per cent slip at a load of approximately 135 h.p. (27 per cent rated load). For a motor of this size, of normal design, the full-load slip with brushes short-circuited may be assumed to be approximately 2½ per cent. Now with the motor running at 10 per cent slip, to short-circuit the motor secondary at the brushes will cause an instantaneous peak of about 250 per cent of rated torque and rated current, *i. e.*, the fluctuations of torque and current will be of a magnitude equal to approximately 200 per cent of rated load. On the other hand, if this equipment were called on to deliver rated load at full speed (*i.e.*, with minimum resistance of the liquid rheostat), the slip would be about 35 per cent, and to short-circuit the liquid rheostat under this condition would obviously be out of the question.

It might be considered possible to short-circuit the liquid rheostat in several steps by means of an ordinary rheostat to be thrown in multiple and cut out in steps. Such an arrangement, however, necessitating several contactors, accelerating relays and a device for interlocking with the liquid rheostat, all in addition to the liquid rheostat itself, would be entirely too complicated to merit serious consideration.

The only proper remedy for the high slip and consequent poor full speed efficiency revealed by Fig. 13 is therefore to use a liquid rheostat with a much lower minimum resistance. Liquid rheostats have been built (at lower costs than required for equivalent secondary control equipments using contactors), in which the slip introduced by the rheostat is not more than 4 per cent at full load.

Louis C. Marburg (communicated after adjournment): This paper is of particular interest on account of its description of a type of control still unusual in this country. The writer wishes to join most emphatically with Mr. Cheney in his statement

that liquid rheostats have not found in America the attention they deserve.

It is a fact known by all those that observe developments in various countries, that invariably it takes a number of years before improvements made in one country, are adopted in other countries. However, the liquid rheostat has surely had more than its due share of waiting in this country before it has found even the slightest favor. Let us remember that the locomotives of the well-known Lecco-Collico-Chiavenna three-phase line in Italy, which was in operation as far back as 1901, use liquid rheostats in regular operation and that innumerable control equipments of this type have been installed in Europe during the last ten years.

Among the most interesting examples were two large liquid type controllers installed at a mine near Essen, Germany, some years ago, for use in connection with two large Ilgner motor-generator sets. When the writer visited the plant in question for the first time, large and extremely expensive control equipments of the metallic resistance type were trying to take care of the large induction motors. They were entire failures and upon his next visit the writer found them replaced by liquid rheostats and everybody was happy.

In advocating these equipments in this country the writer has found rather general opposition. When the hoisting equipment described by Mr. Cheney was constructed, the writer was connected with the company that built this hoist and was in charge of electric hoisting equipments. To convince the customer regarding the merits of liquid rheostats which to the writer, in view of European experience, appeared the only feasible control, was not so difficult. With his own company, however, the writer encountered a general disbelief that the equipment would ever be a success and there were many to prophesy certain disaster. It is only this attitude, which was in line with a dislike of the liquid rheostat still general among engineers, that makes it worth while to call attention to the successful operation of the equipment.

DISCUSSION ON " COMPRESSION CHAMBER LIGHTNING ARRESTER AND THE PROTECTION OF DISTRIBUTION CIRCUITS " (CREIGHTON AND SHAVOR),
" HUMAN ACCURACY: MULTI-RECORDER FOR LIGHTNING PHENOMENA AND SWITCHING " (CREIGHTON, NICHOLS AND HOSEGOOD),
"STUDIES OF PROTECTION AND PROTECTIVE APPARATUS FOR ELECTRIC RAILWAYS " (CREIGHTON, SHAVOR AND CLARK),
" PROPAGATION OF IMPULSES OVER A TRANSMISSION LINE " (CUNNINGHAM AND DAVIS),
" SOME MECHANICAL CONSIDERATIONS OF TRANSMISSION SYSTEMS " (WORCESTER), AND
" ELECTRICAL CHARACTERISTICS OF THE SUSPENSION INSULATOR " (PEEK); SCHENECTADY, N. Y., MAY 17, 1912. (SEE PROCEEDINGS FOR MAY, 1912).

(*Subject to final revision for the Transactions*)

E. M. Hewlett: I am naturally interested in the development of the suspension insulator, which I first brought before the Institute in 1907, at the Niagara Falls meeting. The suspension insulators in their present form are giving excellent service at 110,000 volts and 140,000 volts. Having increased the radius of distribution to more than twice that practicable with the 60,000-volt pin insulator, which seemed to be the limiting factor, we learn from the operating engineers that these insulators are giving satisfaction. The step to 110,000 volts was made with less line trouble than the previous step, due to the higher mechanical and electrical safety factors.

In the original design of the suspension insulator we did not realize what some of the factors that have since turned out to be a help to us, really were, that is, the higher safety factor and the opportunity to allow moisture to collect on both sides, and you will see that these have given us an insulator that under moist conditions will test up better than it does under dry conditions. Lightning generally comes during a rain storm, so our lightning troubles are likely to bother us less with the suspension insulator than if we had the pin insulator. Then the safety factor with the suspension insulator has been greater, and that probably explains the reason for less line trouble with the raise in voltage from 60,000 to 110,000 and to 140,000 volts. We know that Mr. Foot has been running his transmission line in Michigan at 140,000 volts for the last three months, and he says that everything is working very nicely indeed.

The mechanical safety factor of the suspension insulator has allowed or permitted construction on lower voltages, which is cheaper than the pin construction; that is, where a curve is made, or an anchorage is made, you can fasten the suspension insulator to the side of a pole, instead of on an arm, and it gives a very rugged and much simpler construction.

Since this paper was read tests have been made on suspension insulators of various makes, using a suitable transformer capable of delivering 750,000 volts. The curves between arc-over and

number of units show only a slight falling off as the number of units is increased. This would indicate that the peculiar drooping characteristic is largely due to the capacity of the testing transformer.

It would seem from the above that there is still plenty of leeway above the present operating voltage (140,000 volts) before operating conditions will be affected by this phenomenon.

Paul M. Lincoln: I have been very much interested in the paper by Mr. Peek. He has brought out some points in that paper which are of great interest, and it is a line along which I have thought considerably myself. There is one point, however, to which I would call his attention, and that is, whether or not he has correctly analyzed the reason for the wet string of insulators being of higher potential than the dry string.

There are two things which may be noted when a string of insulators becomes wet; first, the resistance of the path across the insulators is lowered. That is, as I understand Mr. Peek, the reason which he ascribes for the difference noted. There is, however, another effect which takes place when the insulator becomes wet, and that is an increase in the area of the conducting surfaces and a consequent change in the relation of the mutual capacity between adjacent disks to that of a disk to ground. It occurs to me it is that change in this relation of capacities that has the larger effect in enabling the wet string of insulators to stand a higher potential than the dry string.

That same consideration has led me, before, to believe that our insulator design for long strings might be made very much better by arbitrarily making the static capacity of those insulators which are next to the conductor higher than those which are nearer the tower. It is quite possible to so design a string of insulators that we change the static capacity of one against the other and make them such that the static potentials will be divided equally across the various insulators. It cannot be done when the mutual capacity is the same all through, but it is quite easy to design a string of insulators and change the static capacities, one against the other, so that the potential across the various insulators will be thereby more evenly divided.

Another point which may be mentioned in connection with the design of line insulators is the fact that on any section of an insulator the static strains at the inside are higher than they are at the outside. Reference to Fig. 6 of Mr. Peek's paper will show what I mean. The insulators partly shown in these sections are subjected to voltage strains which appear between a pin of relatively small diameter as one terminal and an enclosing metallic bonnet as the other.

Now, any one who is familiar with this matter knows at once that the strains across this individual section of a complete string of insulators are by no means evenly divided. The strains at the small diameter of the pin are much higher than they are at the large diameter of the enclosing cap, and here again, it

seems to me, is an opportunity for considerable betterment in the design of insulators. In general, the diameter of the inside pin ought to be increased, and in some cases it would be actually possible, I believe, to reduce the static strains on that part of the insulation next to the small diameter pin by reducing the thickness of the insulating wall.

Referring to Mr. Worcester's paper, if I interpret it correctly, there are no conductors present, on the flexible towers he cites as an example, except the conductors which carry current. In the design of the flexible tower system I consider that the presence of an overhead ground wire will have a considerable bearing. The overhead ground wire has a double value in flexible tower systems. First, it gives the protection which is usually credited to it, of guarding against lightning, and secondly, it has very considerable bearing upon the design with reference to the strains on the wires when any conductor breaks. The ground wire in this case should be made of steel and should have a breaking strength considerably above that of any of the conductor wires which are used. By properly designing these and distributing them at the top of the tower, the condition which Mr. Worcester cites, that the strain on the conductors when one breaks goes considerably above the ultimate strength, does not necessarily follow, since a large part of the longitudinal strains may be taken by the ground wires.

Another point in that connection is the assumption many people make, that the straining of a conductor wire on a tower above its elastic limit is fatal. I do not believe this is the case. Any conductor or other piece of finished metal has been, in the process of its manufacture, continually subjected to such strains. Every wire that is rolled or drawn, during that process of rolling or drawing is subjected to strains beyond its elastic limit. If after it is up it is subjected to strains beyond its elastic limit, it does not mean, in my opinion, that the wire will be damaged; in fact, it is somewhat similar to the process of stretching and drawing, and it is quite conceivable that the wire, as a result of being subjected to strains above its elastic limit, is actually strengthened and not weakened.

R. J. McClelland: I wish to make a few remarks concerning Mr. Worcester's paper with special reference to the use of overhead ground wire as an additional support to the tower, both flexible and rigid, it being especially valuable for the former type.

In the design of a line using the so-called rigid tower, we have taken into consideration the additional support given to the structure by the overhead ground wire; this has consequently reduced the weight of the tower, and thereby decreased the cost of the line. Our experience has not yet indicated that we are in error in our assumptions; in fact, we had an experience which tends to bear out our conclusion.

A 100-kv. double circuit steel tower line constructed last

year with six No. 0 conductors and $\frac{3}{8}$-in. (9.5 mm.) galvanized steel strand as overhead ground wire, was wrecked. The circumstances were as follows: line was completed before the right-of-way was thoroughly cleared, and during a very severe wind storm, a tree was blown into the line, breaking five of the No. 0 conductors. The towers suffered no damage whatsoever. We believe that this fact was due to two reasons:

1. The overhead guard or ground wire. The towers were very recently erected, and we did not consider that the anchorage was first-class; in fact, there had been more or less rain and the ground was not settled around the steel footings, no concrete being used.

2. The strain on the tower was very greatly relieved due to the slack put into the line by the suspension insulators. In this case we had six units, which means that there was slightly over four ft. (1.2 m.) between the cross-arm and the wire, the major portion of which, especially at the first tower, was put into the line, thus relieving the strain on the tower to a very great extent. This is transmitted back, of course, to the succeeding towers to a lesser degree.

It would seem that this last fact has not been given sufficient consideration in connection with either the rigid or flexible tower transmission line construction, and that by taking these two important points into consideration, it should be possible to reduce test loads usually called for in tower design, thereby reducing the cost of construction.

C. Edward Magnusson: ¶ I have received a paper from Mr. Andrew McNaughton, of McGill University, giving the results of an investigation on string insulators which he has recently completed. This paper I wish to present in connection with the discussion of Mr. Peck's paper, as it gives additional data of considerable importance. The theoretical calculations have been made on a somewhat different basis, and present the problem from another point of view. The experimental data are in full accord with the results presented by Mr. Peck, and form an excellent check on the work described in the latter's paper.

Andrew McNaughton (by letter): The object of this paper is to calculate the potential distribution over suspension type insulators and to compare the resulting theoretical flash-over voltages with those actually obtained under test.

In the calculation of the potential distribution regard must be given to the following:

(a) Resistance of the material of the insulator.
Leakage over the surface.

(b) Capacity of a single unit.
Extra capacity between units when two or more are in series.

(c) Voltage, in its effect on capacity and surface resistance, due to formation of corona.

(d) Frequency, as affecting the critical point of corona forma-

tion and the distribution of stress between resistances and capacities in series.

Consider the case where the conductance is so small in comparison to (capacity) × (voltage) × (frequency) that its effect on the potential distribution may be neglected. At voltages below that of corona formation the string of insulators may be regarded as equivalent to a system of capacities C_1, $C_2 \ldots\ldots C_n$, as shown in Figs. 1-5, where

C_1 is the capacity of a single unit.
C_2 is the extra capacity over two units.
. . . .
C_n is the extra capacity over n units.

If the various capacities $C_1\ C_2 \ldots C_n$ are known, the potential distribution may be calculated.

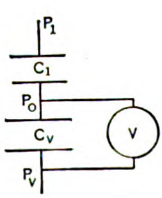


FIG. 1

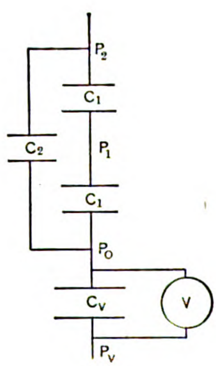


FIG. 2

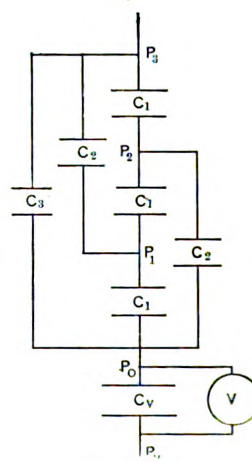


FIG. 3

Fig. 1 shows the diagram of connections used in determining C_1. An electrostatic voltmeter V is shunted across a known capacity C_v which is in series with the insulator unit of capacity C_1, and an alternating voltage is applied to the circuit. The resulting potentials are represented by P_v, P_0 and P_i.

Then

$$(P_1 - P_0) = (V_0) - (P_0 - P_v) \qquad \textbf{(1)}$$

where V_0 is the transformer voltage

$(P_1 - P_0)$ is voltage across capacity C_1

$(P_0 - P_v)$ is voltage across capacity C_v

Equating the charge at P_0 to zero,

$$(P_0 - P_1)\ C_1 + (P_0 - P_v)\ C_v = 0 \tag{2}$$

and

$$C_1 = \frac{(P_0 - P_v)}{(P_1 - P_0)}\ C_v \tag{3}$$

Fig. 2 shows the arrangement with two units. Capacities C_1 and C_2 are involved.

Equating charge at P_0 to zero,

$$(P_0 - P_2)\left(\frac{C_1}{2} + C_2\right) + (P_0 - P_v)\ C_v = 0 \tag{4}$$

and

$$C_2 = \frac{(P_0 - P_v)}{(P_2 - P_0)}\ (C_v) - \left(\frac{C_1}{2}\right) \tag{5}$$

Fig. 3 corresponds to three units in series.

Equationing charge at P_1 to zero,

$$(P_1 - P_0)\ C_1 + (P_1 - P_2)\ C_1 + (P_1 - P_3)\ C_2 = 0 \tag{6}$$

and by symmetry

$$(P_1 - P_0) = (P_3 - P_2) \tag{7}$$

Eliminating P_2 between equations (6) and (7) gives

$$(P_1 - P_0)\ C_1 + (P_1 - P_3 + P_1 - P_0)\ C_1 + (P_1 - P_3)\ C_2 = 0$$

Collecting terms,

$$(P_1 - P_0)\ (3\ C_1 + C_2) = (P_3 - P_0)\ (C_1 + C_2) \tag{8}$$

from which

$$\frac{P_1 - P_0}{P_3 - P_0} = \frac{C_1 + C_2}{3\ C_1 + C_2} \tag{9}$$

and

$$\frac{P_2 - P_0}{P_3 - P_0} = 1 - \frac{C_1 + C_2}{3\ C_1 + C\ 2} \tag{10}$$

Now equating the charge at P_0 to zero,

$$(P_0 - P_v)\ C_v + (P_0 - P_1)\ C_1 + (P_0 - P_2)\ C_2 + (P_0 - P_3)\ C_3 = 0 \tag{11}$$

and

$$C_3 = \frac{P_0 - P_v}{P_3 - P_0} C_v + \frac{P_0 - P_1}{P_3 - P_0} C_1 + \frac{P_0 - P_2}{P_3 - P_0} C_2 \tag{12}$$

Fig. 4 corresponds to four units in series.
By symmetry

$$P_2 - P_0 = \frac{P_4 - P_0}{2} \tag{13}$$

$$P_3 - P_0 = P_4 - P_1$$

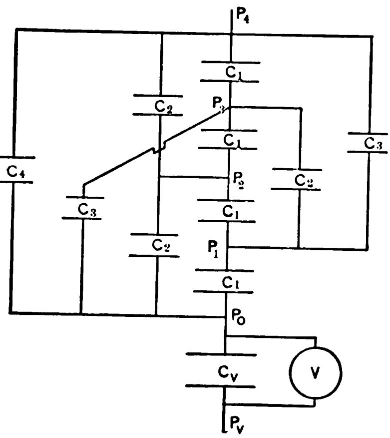


FIG. 4

and equating the charge at P_1 to zero,

$$(P_1-P_0)\, C_1+(P_1-P_2)\, C_1+(P_1-P_3)\, C_2+(P_1-P_4)\, C_4=0 \tag{14}$$

Eliminating P_2 and P_3 between equations (13) and (14), and reducing,

$$(P_1 - P_0)\,(2C_1 + 2C_2 + C_3) = (P_4 - P_0)\left(\frac{C_1}{2} + C_2 + C_3\right) \tag{15}$$

whence

$$\frac{P_1 - P_0}{P_4 - P_0} = \frac{\frac{C_1}{2} + C_2 + C_3}{2\,C_1 + 2\,C_2 + C_3} \tag{16}$$

Equating the charge at P_0 to zero,

$$(P_0 - P_v)\ C_v + (P_0 - P_1)\ C_1 + (P_0 - P_2)\ C_2 \\ + (P_0 - P_3)\ C_3 + (P_0 - P_4)\ C_4 = 0 \quad (17)$$

and therefore

$$C_4 = \frac{P_0 - P_v}{P_4 - P_0}\ C_v + \frac{P_0 - P_1}{P_4 - P_0}\ C_1 \\ + \frac{P_0 - P_2}{P_4 - P_0}\ C_2 + \frac{P_0 - P_3}{P_4 - P_0}\ C_3 \quad (18)$$

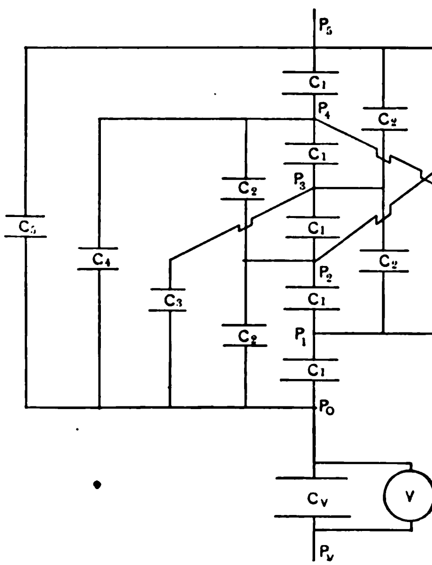


Fig. 5

Fig. 5 corresponds to five units.
By symmetry

$$(P_4 - P_0) = (P_5 - P_1)$$
$$(P_3 - P_0) = (P_5 - P_2) \quad (19)$$

and, equating the charge at P_1 to zero,

$$(P_1 - P_0)\ C_1 + (P_1 - P_2)\ C_1 + (P_1 - P_3)\ C_2 + \\ (P_1 - P_4)\ C_3 + (P_1 - P_5)\ C_4 = 0 \quad (20)$$

Eliminating P_3 and P_4 between equations (**19**) and (**20**), and reducing,

$$(P_1 - P_0)\,(2C_1 + C_2 + 2C_3 + C_4) = (P_2 - P_0)\,(C_1 - C_2) \\ + (P_5 - P_0\,(C_2 + C_3 + C_4) \qquad \textbf{(21)}$$

Similarly, by equating charge at P_2 to zero and eliminating P_3 and P_4 by equation (**19**),

$$(P_2 - P_0)\;(3C_1 + 2C_2 + C_3) \;=\; (P_1 - P_0)\;(C_1 - C_2) \\ + (P_5 - P_0)\;(C_1 + C_2 + C_3) \qquad \textbf{(22)}$$

Combining equations (**21**) and (**22**),

$$\frac{P_1 - P_0}{P_5 - P_0} = \frac{\dfrac{(C_1 - C_2)\,(C_1 + C_2 + C_3)}{(3\,C_1 + 2\;C_2 + C_3)} + \;(C_2 + C_3 + C_4)}{(2C_1 - C_2 + 2C_3 + C_4) \;-\; \dfrac{(C_1 - C_2)^2}{(3\,C_1 + 2\,C_2 + C_3)}} \qquad \textbf{(23)}$$

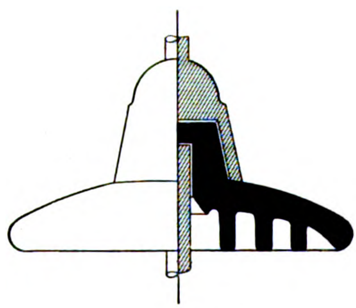


FIG. 6

$$\frac{P_2 - P_0}{P_5 - P_0} = \frac{\dfrac{(C_1 - C_2)\,(C_2 + C_3 + C_4)}{(2\;C_1 + C_2 + 2\;C_3 + C_4)} + (C_1 + C_2 + C_3)}{(3\;C_1 + 2C_2 + C_3) - \dfrac{(C_1 - C_2)^2}{2\;C_1 + C_2 + 2\,C_3 + C_4}} \qquad \textbf{(24)}$$

Equating the charge at P_0 to zero,

$$(P_0 - P_v)\;\;C_v + (P_0 - P_1)\;\;C_1 \ldots . (P_0 - P_5)\;\;C_5 = 0 \qquad \textbf{(25)}$$

whence

$$C_5 = \frac{P_0 - P_v}{P_5 - P_0}\,C_v + \frac{P_0 - P_1}{P_5 - P_0}\,C_1 + \ldots . \frac{P_0 - P_4}{P_5 - P_0}\,C_4 \qquad \textbf{(26)}$$

Similarly for six units:
By symmetry

$$P_5 - P_0 = P_6 - P_1$$
$$P_4 - P_0 = P_6 - P_2$$
$$P_3 - P_0 = \frac{P_6 - P_0}{2} \qquad (27)$$

and, equating charge at P_1 to zero,

$$(P_1 - P_0)\, C_1 + (P_1 - P_2)\, C_1 + (P_1 - P_3)\, C_2 \ldots . (P_1 - P_6)\, C_5 = 0 \qquad (28)$$

Eliminating P_3, P_4 and P_5 between equations (27) and (28), and reducing,

$$(P_1 - P_0)\,(2\,C_1 + C_2 + C_3 + 2\,C_4 + C_5) = (P_2 - P_0)\,(C_1 - C_3) + (P_6 - P_0)\left(\frac{C_2}{2} + C_3 + C_4 + C_5\right) \qquad (29)$$

Equating the charge at P_2 to zero,

$$(P_2 - P_0)\,C_2 + (P_2 - P_1)\,(C_1) + (P_2 - P_3)\,(C_1) + (P_2 - P_4)\,C_2 + (P_2 - P_5)\,C_5 + (P_2 - P_6)\,C_4 = 0 \qquad (30)$$

and, eliminating P_3, P_4 and P_5 by equation (27),

$$(P_2 - P_0)\,(2C_1 + 3C_2 + C_3 + C_4) = (P_1 - P_0)\,(C_1 - C_3) + (P_6 - P_0)\left(\frac{C_1}{2} + C_2 + C_3 + C_4\right) \qquad (31)$$

Eliminating P_2 or P_1 between equations (29) and (31),

$$\frac{P_1 - P_0}{P_6 - P_0} = \frac{\dfrac{(C_1 - C_3)\left(\dfrac{C_1}{2} + C_2 + C_3 + C_4\right)}{(2\,C_1 + 3\,C_2 + C_3 + C_4)} + \left(\dfrac{C_2}{2} + C_3 + C_4 + C_5\right)}{(2\,C_1 + C_2 + C_3 + 2\,C_4 + C_5) - \dfrac{(C_1 - C_3)^2}{(2\,C_1 + 3\,C_2 + C_3 + C_4)}} \qquad (32)$$

and

$$\frac{P_2 - P_0}{P_6 - P_0} = \frac{\dfrac{(C_1 - C_3)\left(\dfrac{C_2}{2} + C_3 + C_4 + C_5\right)}{(2\,C_1 + C_2 + C_3 + 2\,C_4 + C_5)} + \left(\dfrac{C_1}{2} + C_2 + C_3 + C_4\right)}{(2\,C_1 + 3\,C_2 + C_3 + C_4) - \dfrac{(C_1 - C_3)^2}{(2\,C_1 + C_2 + C_3 + 2\,C_4 + C_5)}} \qquad (33)$$

Now equating the charge at P_0 to zero,

$$(P_0 - P_v)\,C_v + (P_0 - P_1)\,C_1 + \ldots\,(P_0 - P_6)\,C_6 = 0 \qquad (34)$$

whence

$$C_6 = \frac{P_0 - P_v}{P_6 - P_0}\,C_v + \frac{P_0 - P_1}{P_6 - P_0}\,C_1 \ldots \frac{P_0 - P_5}{P_6 - P_0}\,C_5 \qquad (35)$$

In like manner for seven or more units the capacity and potential coefficients may be derived and hence the potential distribution calculated.

Fig. 7 gives the results of a set of observations taken on units similar to that shown in Fig. 6.

The frequency was 53 ~ per sec.

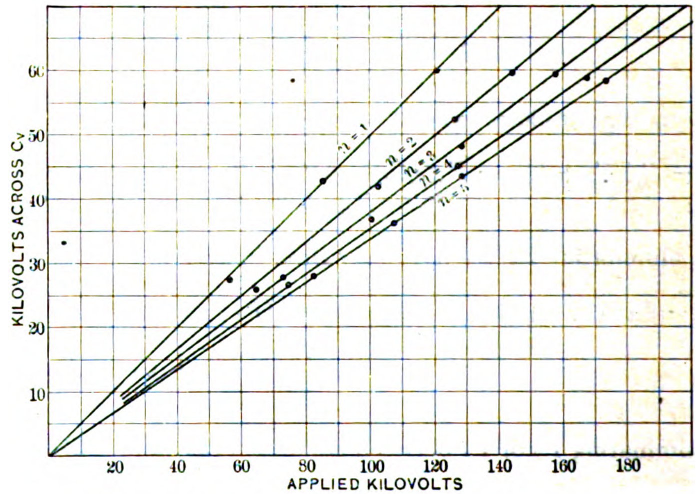


FIG. 7—VOLTS ACROSS C_v WITH n UNITS IN SERIES

The voltage was controlled by resistance in the alternator field and measured by the auxiliary coil method and by electrostatic voltmeter.

Fig. 8 gives the calculated capacity coefficients.

Fig. 9 shows the resulting potential distribution over the units in strings of different lengths.

The ordinates represent percentages of what the stress would be if it were uniformly distributed. For example, in a string of four units the stress on the end unit is 130 per cent, on the second unit is 70 per cent, on the third unit 70 per cent, and on the fourth or other end unit 130 per cent.

Fig. 10 gives the calculated flash-over voltage on the assumption that the failure of a string occurs at the same stress on the

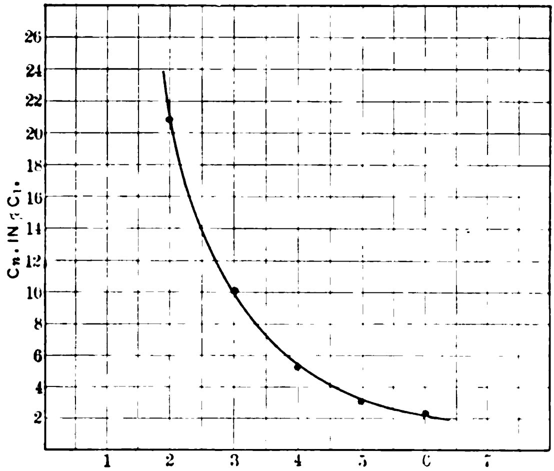


FIG. 8

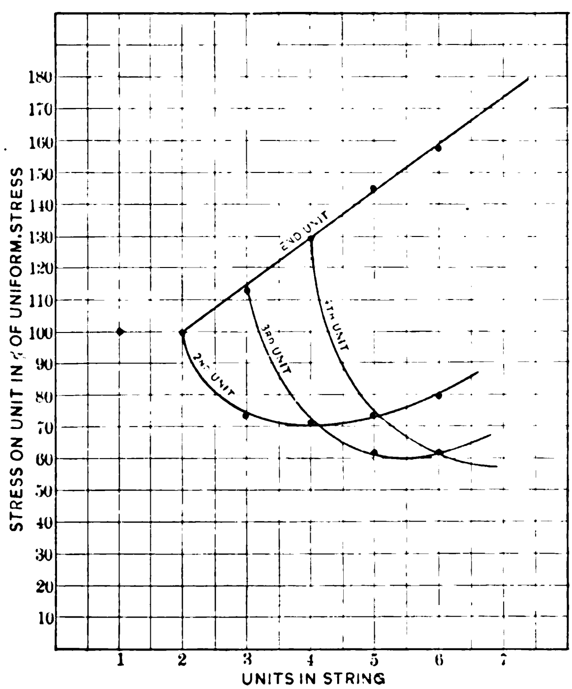


FIG. 9—POTENTIAL DISTRIBUTION

end unit in each case, that is, the breakdown of the end units causes the remainder to fail by concentrating on them nearly the whole of the voltage.

The units in strings of two or three fail by flash-over of the insulator as a whole, and this occurs at a lower value of voltage than that corresponding to successive breakdown. The test points lie below the calculated.

With four units, Figs. 11, 12 and 13 show failure both by successive discharge and by air arcing. At this number of units the calculated and test curves cross.

With five or more units the failure is due to the unbalanced potential distribution, that is, to successive discharge, and occurs

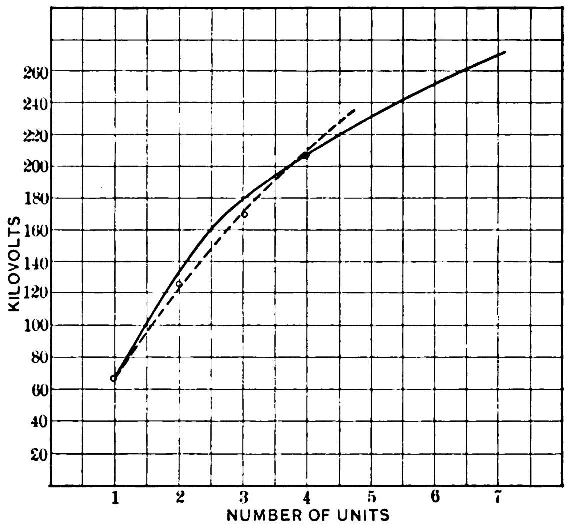


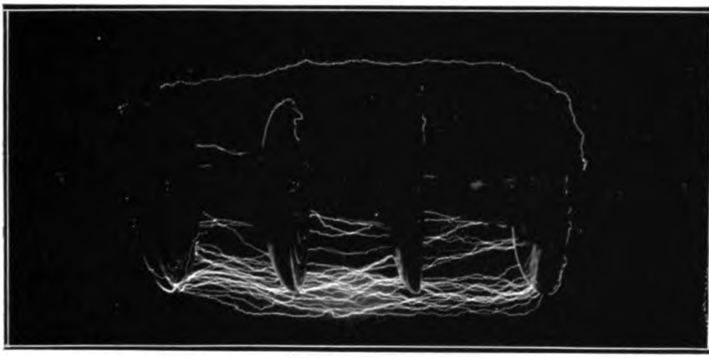
FIG. 10—CALCULATED FLASH-OVER VOLTAGE
0 = Test Points

at a higher voltage than calculated because of the auto-grading of capacity produced by corona.

The capacity of the various units against ground may be inserted in the equations and evaluated by taking readings with successive points of the transformer winding grounded, thus giving P_0 definite arbitrary values.

If the capacity to ground were appreciable in comparison with C_1, C_2, etc., the flash-over voltage would vary with the value of P_0.

Flash-over tests were made under these conditions but no appreciable difference could be detected from the results obtained with the neutral grounded; for this reason the capacity to ground has been neglected. Its general effect, if present, would



[MC NAUGHTON

FIG. 13

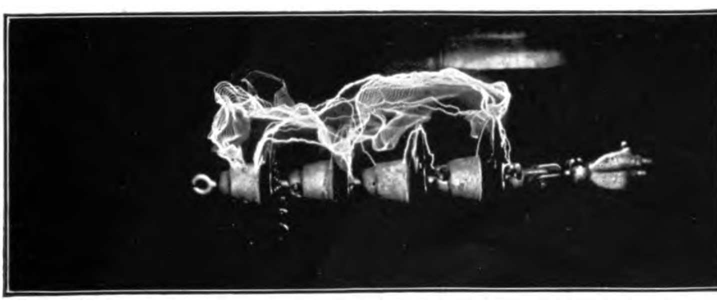


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FIG. 12

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FIG. 11

be to make the potential distribution asymmetrical, throwing more stress on the units to the line and less on those next to the tower.

For high-frequency surges the potential distribution is indicated more correctly by the calculated curve of Fig. 10 than by the test results, for, because of the time-lag of corona formation, auto-grading is absent.

The effect of increased conductance by deposition of moisture on the surface is to even out the potential distribution over the various units and it is even possible that where the failure is by successive discharge the insulator will flash over at a higher voltage wet than dry.

These results show that in order to improve the characteristics of suspension type insulators the capacity should be graded to have the larger units near the line and tower and the smaller at the center of the string, to even out the symmetrical unbalancing, and with perhaps the line unit slightly the larger to take care to the effect of any ground capacities which may be present.

The experimental work of this investigation was carried out at the high-voltage laboratory of McGill University in conjunction with Mr. O. F. Hague and under the direction of Dr. L. A. Herdt.

Harris J. Ryan (by letter): Some tests were made in March, 1912, for the Bureau of Los Angeles Aqueduct Power, to determine the manner in which capacity to neighboring unit, capacity to ground, capacity to the line conductor, corona, water vapor and rain conduction, damp dusty surface conduction, etc., affect the voltage duty of the individual unit, or the "grading," as it is called in the present paper. Table I shows unit voltage duties obtained in these tests for the dry six-unit suspension insulators:

TABLE I

Number of units	Kilovolts across unit	Kilovolts across unit	Kilovolts across unit
1	10.3	12	18.4
2	12	14.1	21.7
3	11.9	13.9	15
4	7.2	8.4	21.6
5	6.3	7.3	11.7
6	6.3	7 3	11.6
Total	54	63	100

Other data:

e_1 = flash-over in kilovolts per single unit = 76; altitude at which test was made, 3900 ft. (1189 m.) above sea level; e_1 at sea level given by manufacturer, 90.

c_2/c_1 = ratio of mutual to ground capacities, not measured, supposed to be about 25.

Ordinary temperature and barometric values existed during the tests.

Top unit grounded as on tower.

Bottom unit three ft. (91 cm.) from ground supporting No. 0000, B. & S., line cable.

These six-unit insulators may be considered as having a normal voltage to ground rating of 54 kilovolts.

In complete darkness no trace of visible corona appeared over any part of the insulator under the application of less than 100 kilovolts.

The frequency used in the tests was 60.

Corona appeared on the No. 0000 line conductor at 63.0 kilovolts. It must be remembered that this was a single-phase circuit in which the line conductor was held three ft. (91 cm.) above the ground. The importance of the capacities of the units to the line conductor as a factor controlling the voltage duties of the individual units was brought out by the fact that

TABLE II

	Kilovolts across each unit		
Number of units	Theoretical (Peek)	Aqueduct Power	
		54 kv.	100 kv.
1	100	80.3	77.5
2	83	93.5	91.1
3	71	92.7	63
4	62	56.3	91
5	57	49.1	49.2
6	48	49.1	49.2
Total	421	421	421
Eff. per cent	70.2	75	77

the unit next to the line conductor did not in any of the tests sustain the highest voltage duty; such highest drop in voltage occurred usually across the second unit above the line conductor, though sometimes the third or even the fourth unit was subjected to about the same duty as the second.

The effect of conduction in the atmosphere produced by corona on the line conductor is brought out by the change in the insulator efficiency taken in the same manner as described in Mr. Peek's paper. Thus at 54 kv. the efficiency is 74.5 per cent; at 63 kv., just at the corona start, the efficiency is unchanged, and at 100 kv. it has increased to 77 per cent. The efficiency would continue to increase slowly as the voltage is raised until the insulator failed through a cascading flash-over. At the efficiency of 77 per cent the insulator would fail at $6 \times 76 \times 0.77 = 350$ kilovolts. It is a fact, as just noted that, the increased corona at flash-over would increase the efficiency by a

small amount and therefore this value of 350 kv. would be slightly increased correspondingly.

The $e_1 = 74$ and $c_2/c_1 = 20$ insulator of Fig. 19 in the paper is almost identical in characteristic make-up with the insulator employed in the Aqueduct Power tests. The curve in the figure shows that the suspension insulator in Mr. Peek's test flashed over for six units at 325 kv., which is in fair agreement with the above value of 350 kv., considering the differences in c_2/c_1.

In Table II the *theoretical* values are taken from the interpolated curve, $e_1 = 100$, $c_2/c_1 = 20$, $n = 6$, of Fig. 14, for the voltage duty of individual units as computed by Mr. Peek, using his theoretical method. The *Aqueduct Power* values are those given in Table I at 54 and 100 kilovolts, scaled to the same total voltage used by Mr. Peek, to facilitate comparison.

In comparing these values it is also well to remember that the Aqueduct Power insulator had a higher value of mutual to ground capacity ratio than the insulator used in Mr. Peek's tests.

The results of our dry insulator tests show that while the voltages across the individual units are quite different from the theoretical values obtained by Mr. Peek, such differences are largely *compensating*, so that substantially the same over-all actual efficiencies are obtained.

Experience has shown that the unit next to the line conductor is the one in a set most apt to puncture. It is not the one subjected to the highest operating voltage. Normal puncture voltage is made to exceed flash-over voltage by 20 to 50 per cent, dependent upon design and altitude. These facts indicate that the puncture is due to the application at the insulator of voltage higher than the flash-over value so suddenly that puncture takes place before corona has time to develop sufficiently to concentrate into a flash-over. This accords with the possibilities made evident by experimental physics and with the views expressed in the paper.

In Mr. Peek's present paper all known factors that unite to bring about the failure of a suspension insulator are analyzed and the results of many tests are given. These analyses and tests have demonstrated unmistakably that over a wide range of types and operating conditions the single-unit flash-over voltage, e_1 and the mutual-to-ground capacities ratio, c_2/c_1, are truly the "bench marks" of the characteristic topography of the suspension insulator.

Practically, in any given endeavor, the contributing factors are varied and numerous. A few factors, however, are generally responsible for the characteristic results produced and the rest work for and against such results—they do not in the aggregate have much effect. At best a theory can correlate and apply only a few factors. A useful theory must rest upon a thorough knowledge of all factors, those that have been excluded as well as those that have been included. The present paper is of much value, therefore, because of the success with which the

theoretical factors have been separated from the total mass of factors that bring about the aggregate behavior of the suspension insulator.

R. P. Jackson: In regard to the compression chamber lightning arrester, my experience has been that when non-arcing gaps are enclosed in a chamber of any kind, or when gaps, in fact, are enclosed in a chamber where rapid discharges take place, the metal fumes tend to make a continuous arc. It is well known that in unit switches, or any place where fumes of metal go out into the insulating spaces, these fumes will cause the arc to jump long distances, so, while not questioning the results obtained in the experiment, I am somewhat surprised at the effort to produce an arrester using a gap in an enclosing chamber, where the fumes cannot escape.

In regard to the protection of the single-phase railway motors, the single-phase system generally has sustained no injury from lightning, and practically nothing has been necessary in the way of protection of the motor, because the motors are on the low-tension side of an auto-transformer. The auto-transformer very seldom suffers, as it is rugged and strong and well insulated.

High-voltage direct current is not subject to any such automatic or natural protection. The motors are at least as vulnerable as the old 500-volt direct-current, and the higher voltage and the higher insulation of the line, and the greater number of turns in the armature, undoubtedly make the high-voltage direct-current system weak in this respect.

That is a direction in which experiments must be carried out, and in which the results given in the paper indicate good work has been done, and will have to be continued, to make high-voltage direct current as reliable as the old 500-volt direct current, because it is the one weak spot in that system.

It may be said that the experience with the ordinary railway motor is that the new motors do not suffer from lightning. The trouble is not with the new equipment, but with re-wound motors, motors which have been in service, which have had their armature cores bruised and new coils put in. The new coils which are put in may not be as strong as the original ones, and there is where the difficulty appears. This will also be true of the high-voltage direct-current motors coming into use.

The direct-current electrolytic arrester is the most effective arrester for protecting motors, generators and anything of that kind. I should like to know if it has been found that operating men in general will give the necessary care to such a sensitive and fragile device—they are more or less sensitive and require some care and attention. Psychologically, the condition is the same as when a man is cured of a trouble—he neglects the remedy, and the trouble recurs. The use of such a sensitive protective device would apparently be subject to the same psychological condition.

The insulator question is of great interest. I notice the fact

that wet insulators have a higher flash-over voltage than the same insulators dry. It is a curious fact that while lightning is supposed to occur, usually, during thunder storms, it does not always so occur, and storms which are attended with lightning, both on the line and the power equipment, are most serious just before the rain begins to come down, when everything is dry. The insulators are more readily damaged, the lightning goes into the power house, and generally the dry line brings about lightning troubles which are a good deal worse than those coming after the insulators are all wet.

There is no mention of the fact that the insulators on the line, when all wet and leaking slightly, make good lightning arresters; and suddenly the lightning trouble vanishes because the rain has come down and made each insulator a mild lightning arrester. It would seem to me, that an insulator which was designed so that its action would be about the same, either wet or dry, would be an excellent design; that is, it would not be likely to fail or suffer when it was wet, and would be equally good dry.

I was somewhat surprised to learn that there is a difference in the quality of the water. It is mentioned in the paper that highly conducting water, or non-conducting or high-resistance water, makes a marked difference in the insulator voltage flash-over. How is it with rain? Is rain, being a distilled water, a highly resisting water, or can it be considered, as in Pittsburgh, for example, a pretty good conducting water?

Charles P. Steinmetz: These papers are so complete that I have practically nothing to add, but want to draw your attention to a very interesting phenomenon which is contained in the subject matter of two of these papers, that on the compression chamber lightning arrester, and the one on the suspension insulator. What I refer to is the potential distribution in a circuit containing distributed capacity in two different forms, as distributed series capacity and as distributed shunted capacity. In the compression chamber lightning arrester we have the capacity between adjacent disks and also the capacity of each disk to ground, the former a series, the latter a shunt capacity. In the string insulator we have the capacity across each insulator and the capacity from the connection between adjoining insulators tc ground. In such a system the potential distribution is not uniform, but the potential is higher at some places than at others. You will see that the problem which is dealt with in the two papers is just the reverse one. In the suspension insulator the problem is to get as uniform potential distribution as possible. In the compression chamber lightning arrester the problem is to get as ununiform potential distribution as possible, that is, to concentrate as much potential as possible across the first condenser.

This is obvious, because in the suspension insulator the purpose is to hold back as high a voltage as possible with a

minimum number of condensers. In the compression chamber lightning arrester the object is to be able to use as many condensers in series as possible with the same breakdown voltage, so as to get the arc-rupturing effect of as many gaps in series as you can get. So you see there is the same phenomenon applied in two opposite directions.

The phenomenon was recognized first in the early days of the multi-gap lightning arrester, when the attempt was made to develop it for very high voltages and, as we know, that attempt failed due to this phenomenon. It was not possible to design multi-gap lightning arresters for 60,000 volts and over within any reasonable size, due to the phenomenon of unequal potential distribution by the combination of shunt and series capacity.

There is one interesting conclusion or suggestion which may be drawn from a consideration of the string insulator. We have seen that as near uniform potential should be secured as possible, to get higher break-down, and also the equations given in the paper show that the potential distribution between the insulators is independent of the frequency, that with two capacities acting in combination, each capacity takes a current proportioned to the frequency, so that in the relative currents and the relative distribution of potential, the frequency does not come in, apparently. However, in reality, when you come to very high frequencies, the frequency does seem to come in, because experience shows that in a transmission line very high frequencies, like oscillating discharges, lightning discharges, etc., act differently in their disruptive effect from low frequency. At the relatively low test frequency such an insulator string flashes over the whole string without puncturing. We find that very high frequencies, such as lightning, have the effect of puncturing the insulator nearest to the line, showing that the distribution at these extremely high frequencies is more ununiform.

An explanation of this may be the equalizing effect of the brush or corona discharge, which changes or increases the capacity of the insulator near the line, where the voltage is higher, and so evens out the potential distribution. Then the conclusion which we would have to draw, at least the suggestion which presents itself, is that at very high frequency brush discharge or corona does not act to equalize the potential distribution. That means that the brush discharge does not appear, or in other words, it seems to point to the conclusion which other phenomena also have made probable, that corona or brush discharge is not an instantaneous phenomenon, but is a phenomenon which requires some appreciable time to develop—that when you apply a very high voltage the corona does not instantly rush out from the conductor, but gradually builds up the stresses from the insulator, and therefore, if the voltage is instantly applied at very high frequency, there is no brush discharge or corona, or at least a very small corona, while at low frequencies the corona exists.

I think this is a suggestion which is worthy of further investigation, because naturally brush discharge and corona at high voltages is an important factor, which determines potential distribution, and if it should not exist at some frequencies while existing at other frequencies, then we would not be able to judge of the potential distribution at high frequencies from that at low frequencies, and we would not be able to judge of the disruptive strength of the apparatus and its reliability at high frequency from that at low frequency.

Charles F. Scott: These papers seem to me, as a group, to be an admirable presentation of a combination of theory and mathematics, of simple things, of manufacture, of engineering design, of operating conditions, and of looking forward to the future to the new and larger work which is to come. It is a remarkable group of papers.

A striking feature of these papers is that they present simple things. I can scarcely recall a new principle involved in these papers, but there are new ways of doing things, combinations of simple things in condensed form, and fundamental elements of electrical engineering and of mechanical engineering are utilized in a way to meet new problems in new ways.

Some of the papers, notably those on lightning arresters, will be recognized by some of the older of us as another step in the progress which has been going on for twenty years. This old so-called non-arcing lightning arrester had its beginning some twenty years ago, and has evolved one step, and then another, and then another, and is now attaining a very simple and obvious form by which to accomplish the results which have been aimed at all these years.

I think that, as representing the Institute at large, we ought to commend the excellent work which is being done here by this corps of engineers of the manufacturing company, and the policy of that company in doing this kind of pioneer work. It is not in a narrow sense—merely making and selling machines, but it is doing that large kind of engineering work that is needed for the transmission interests of the country and for that larger electrical progress in which we are all concerned. So that I am sure that what I may say in commending the good constructive work which is now being done here will be acquiesced in by the Institute members from abroad, and we all join in a hearty expression of our appreciation of its presentation before us.

R. Philip Clark: A question has been raised as to the maintenance and care of the direct-current aluminum arrester. At the time this arrester was first placed in commercial operation, several years ago, the principles involved were quite new and the operating characteristics were so radically different from those of any other arrester, that it was only rarely that the aluminum arrester received proper attention. As a result of these and other conditions the arresters often failed to have a satisfactory life.

The arrester has been improved since its first appearance, both in design and in the materials used. The addition of the balancing resistance has overcome the unbalancing of potential across the cells and has thus eliminated one of the most undesirable characteristics of the arrester. Subsequent improvements in electrolyte and aluminum plates have made possible a much longer life than was obtained with the first arresters. However, when direct-connected to the line this arrester has only a moderate life as compared with the gap-resistance type of arresters. In view of this, the use of the direct-connected direct-current aluminum arrester is at the present time generally restricted to installations where the service is very important or the lightning conditions very severe. Periodic inspection of the arresters is essential and the frequency varies from once a week to once a month, or at even greater intervals, depending upon the local operating conditions. Renewals of electrolyte and plates are likewise governed by the conditions of service, but generally average once every two years.

Another type of direct-current aluminum arrester has been developed for car service which is much more satisfactory from the standpoint of maintenance and care. This arrester, which is provided with a series vacuum gap, has a protective value which is only slightly inferior to the direct-connected aluminum arrester. The motion of the car causes the arrester to be automatically charged by means of a special charging gap. A suitable resistance is placed in series with the charging gap to prevent a destructive charging current whenever the arrester has been out of service for any length of time.

It is expected that this latter type of arrester will have a useful life of three to four times that of the direct-connected aluminum arrester. In addition to this, the gap type of aluminum arrester is much better adapted to street car service, as it requires no special precautions when a car is replaced in service after a period of idleness.

Cassius M. Davis: Since the paper by Mr. Cunningham and myself was written, an effort has been made to account for the rather large discrepancy in the values of the length of the line as determined from the measured inductance and capacity and as determined from the oscillograms.

The first check made was the actual measurement of the natural period of the line. For this purpose the line was connected to a small high-frequency generator. Oscillograms were taken of the charging current of the line, at various frequencies above and below the resonance frequency. Each oscillogram also showed a 60-cycle timing wave. A constant potential of 120 volts was impressed upon the line by the generator and the charging current was read on an ammeter in series. The curve plotted between frequency and charging current shows resonance at 353 cycles. This figure corresponds very closely to 363 cycles as calculated from the measured values of inductance and capacity.

The second check comes as a result of the measurement of the speed of propagation from oscillograms which record only the currents of the impulses.

It was suspected that the current taken by the oscillograph vibrators which were used to indicate the voltage of the impulses might act as a serious leakage conductance, and, if this were so, oscillograms which showed no voltage curves would give a more nearly correct value of the time of propagation from which the length of the line could be determined. This was found to be the case, and the average length of line comes out to be in one case 126 miles (203 km.) and in another 132 miles (212 km.), the average of which, it will be seen, is almost exactly the same as calculated from the measured line constants, 128 miles (206 km.).

T. A. Worcester: I wish to express my appreciation of the remarks made by Messrs. Lincoln and McClelland in connection with the ground wire assisting in the support of transmission towers. I agree entirely with their opinion. As to Mr. Lincoln's remarks regarding the stretching of conductors, I think it is dangerous to allow for the conductor to stretch. The stretching of the conductor, while mounted on the transmission line, will not be the same as when it is being drawn in manufacture. Stretching of the transmission wire will probably occur at the cable clamp or tie wire, or at some weak place in the span, and the section of the conductor at that place will be reduced so that a future break will undoubtedly occur there.

In connection with the remarks of Mr. McClelland on the suspension type of insulator, I do not believe it would be desirable to allow very much for the extra length thrown in the conductor when the wire breaks, by the length of the suspension insulator itself. The length of the insulator is not added to the conductor until the wire actually breaks, and then it is useless. Further, when the wire does break, and the insulator is drawn up to a horizontal, instead of vertical, position, there is a very severe jerk on the tower, likely to wrench the cross-arms and loosen them.

F. W. Peek, Jr.: I want to elaborate a little on the point that Mr. Lincoln has brought out in regard to increasing the capacity of the line unit. Decreasing the thickness of the porcelain between pin and cap on the units of a string, by increasing the mutual capacity without changing the capacity to ground, may often actually increase the arc-over voltage of the string. For high string efficiency the problem is to make c_2/c_1 as high as possible. There is also a best ratio between pin diameter and cap diameter for mimimun stress on the porcelain next to the pin—that is for a given internal diameter of cap the puncture voltage may often be increased by increasing the diameter of the pin and thereby decreasing the thickness of the porcelain.. With regard to the effect of rain in improving voltage distribution, the leakage current through the water is generally very large com-

pared to the capacity current, and therefore predominates in the balancing effect.

In the equations the effect of the line conductor, as being slightly greater on the unit nearest the line, is not considered. This would complicate matters to a great extent without adding in any way to the value of the equations. The effect is to slightly lower the voltage on the first unit. The actual string voltage and efficiency is not, however, appreciably changed from values calculated from the equations. I have read Professor Ryan's discussion with great interest. Taking the data given for the Aqueduct Power insulator,

$$e_1 = 76, \quad \frac{C_1}{C_2} = 25, \quad n = 6,$$

from Table X in *Electrical Characteristics of the Suspension Insulator* we find by interpolation $k = 6.5$. Then from equation (4*a*)

$$E_a = \frac{e_1 x}{k - 1} = \frac{76 \times 25}{6.5 - 1} = 345$$

This checks fairly well with Professor Ryan's result. It would have been interesting if Professor Ryan had indicated the method by which the voltages across individual units were measured. In making this measurement it is difficult to find a means whereby the voltage balance will not be changed by the measuring instrument. We have made a number of such measurements, the values of which check fairly well with the theoretical ones, but we have never been quite sure that the voltage distribution was not changed by the measuring instrument.

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PROCEEDINGS

OF THE

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OF

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Lindsley Bros. Co , Spokane, Wash.

PUBLICATIONS, TECHNICAL.
Van Nostrand Co., D., New York, N. Y.

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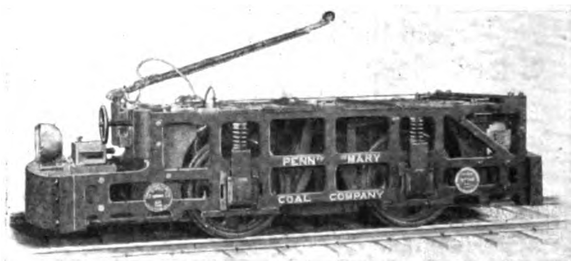

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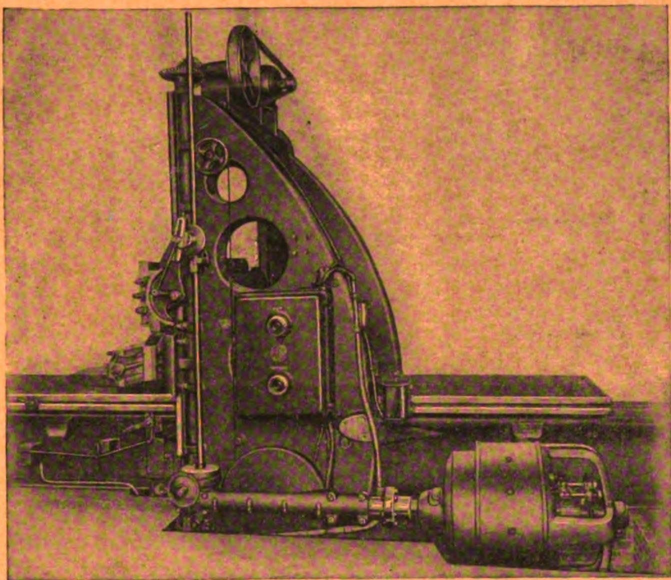

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